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ANALYSIS OF FACTORS AFFECTING AEROSOL, UNATTACHED FRACTION AND RADON PROGENY MEASUREMENTS IN MINES

by

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ABSTRACT

Data from measurements of unattached fractions and aerosol and activity size distributions obtained in Elliot Lake uranium mines in Jan/Feb 1985 are analyzed in detail. The results can be summarized as follows:

(a) approximating the bimodal activity size distribution - one mode is the unattached fraction, the other mode is the attached fraction - by a unimodal distribution (for the attached fraction) is justified for up to at least an assumed 10% unattached fraction. This assumed unattached fraction is subtracted from the counts on the reference filter in the procedure for examining the validity of the approximation. The effect of the approximation on the median diameter of the aerosol is negligible.

(b) the unattached fraction determined from the difference in reference and back-up filter activities is much more accurate when based on gross alpha counts than when based on radionuclide concentrations calculated from the filter activities.

(c) calculation of the unattached fraction from counts on the wire screen and on the reference filter yields smaller unattached fractions than from counts on the reference and on the back-up filter, for reasons not understood. The overall precision of measurement for the wire screen method, however, is much poorer than for the reference-back-up method for both gross alpha counts and radionuclide concentrations.

(d) theoretical determination of the unattached fraction is very sensitive to the age of the air, especially for relatively young air (age<20min). It should, however, be noted that the age of the air concept may not be strictly applicable to mine air since mine air is usually mixed from various sources. The hybrid theory of attachment describes the attachment mechanism best. Unattached fractions determined by this theory are consistent with those calculated from the reference and back-up filter measurements. The

use of a single count median diameter rather than the complete size spectrum of aerosols introduces large errors in the theoretical determination of unattached fraction, especially for Pb-214 and Bi-214.

The measurement methodology, mine data, details of the data analysis techniques, and the results are all presented in this report.

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RÉSUMÉ

Les résultats des mesures de la fraction libre, de la distribution en dimension et en activité des aérosols, obtenus dans les mines d'Elliot Lake en janvier/février 1985, sont analysés en détail. Les résultats peuvent être résumés comme suit:

a) l'approximation de la distribution bimodale (un mode représentant la fraction libre, l'autre la fraction attachée) des aérosols radioactifs à une distribution unimodale est justifiée tant que la fraction libre ne dépasse pas 10%. Les désintégrations dues à cette fraction libre supposée sont soustraites des comptages du filtre de référence afin d'examiner la validité de cette supposition. L'effet de cette approximation sur la détermination du diamètre médian des aérosols est négligeable.

b) la fraction libre est mesurée avec plus de précision à partir de la différence d'activité entre le filtre de référence et le filtre placé derrière une grille de tamis si le calcul est basé sur les comptages alpha totaux au lieu des concentrations des produits de filiation.

c) pour des raisons non expliquées, la fraction libre calculée à partir des comptages de la grille métallique et du filtre de référence est plus petite que celle calculée à partir du filtre de référence et du filtre placé en aval de la grille. La précision globale de la mesure basée sur le comptage de la grille est cependant beaucoup plus faible que celles basées sur les mesures filtre de référence - filtre aval, et ceci dans le cas où la fraction libre est déterminée à partir des comptages alpha totaux et à partir des concentrations de produits de filiation.

d) la détermination théorique de la fraction libre est très sensible à l'âge de l'air, spécialement en-dessous de 20 minutes. On doit cependant noter que la notion d'âge de l'air n'est peut-être pas strictement applicable à l'atmosphère d'une mine, en raison des

mélanges de flux d'air de provenances différentes. La théorie hybride d'attachement donne la meilleure description du mécanisme d'attachement. Les fractions libres déterminées par cette théorie sont en accord avec celles calculées à partir des mesures basées sur le système filtre de référence - filtre aval. L'utilisation d'une seule valeur du diamètre médian en nombre de l'aérosol, plutôt que du spectre complet de dimensions, introduit de larges erreurs dans la détermination théorique de la fraction libre, en particulier pour Pb-214 et Bi-214.

Les méthodes de mesures, les résultats des mesures en mine, les détails des méthodes d'analyses des résultats, et les résultats de l'analyse sont présentés dans ce rapport.

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1.0 INTRODUCTION

Experimental measurements were made in January/February 1985 in Elliot Lake uranium mines in order to determine the unattached fractions and the aerosol and activity size distributions in both track and trackless mines. The present report constitutes a detailed analysis of the experimental data obtained in the mine measurements. The main objectives of this data analysis are:

(a) to determine quantitatively the influence of the unattached fraction on the activity size distribution.

(b) to determine the unattached fractions of mixtures of radon and thoron decay products from the gross alpha activity of air samples obtained in each of the four counting intervals.

(c) to obtain estimates of unattached fractions from gross alpha activity counted on wire screens.

(d) to determine the unattached fractions from the aerosol concentration and particle diameter data for air of age 5, 10, 20, 40, 60 minutes using a theoretical attachment model.

The data, methods of analysis and the results are presented here together with a detailed discussion of several factors which may influence the data analysis.

2.0 METHODOLOGY

2.1 Aerosol and Activity Size Distribution

Since the total number size distribution of the aerosol and the activity size distributions (size distribution of aerosols to which particular radioactive atoms are attached) are not identical, in general, they must be determined separately.

To describe the aerosol size distribution in the atmosphere and in mines, a lognormal size distribution function may be used (Da74):

$$C(d) = \frac{1}{d\sqrt{2\pi}\ \ln \sigma_g} \exp\left(-\frac{1}{2}\left(\frac{\ln(d/\bar{d})}{\ln \sigma_g}\right)^2\right) \qquad (1)$$

where $dC(d)$ = number size distribution function, $n(d)$

$\bar{d}$ = count median diameter of the distribution

σ_g = geometric standard deviation of the distribution

d = particle diameter.

The count median diameter and the geometric standard deviation can be determined using equation (1) and experimental data obtained from diffusion batteries (Bu80). A diffusion battery is an assembly of cylindrical or rectangular channels. The relative penetration of aerosols through different sizes of diffusion batteries at specified flow rates allows the aerosol size distribution to be calculated.

Three diffusion batteries were used in conjunction with a portable (Environment One) condensation nuclei counter and a flow-regulated Dupont pump (Model P-4000). Air was first drawn through the sample port of the condensation nuclei counter by the pump to record the total aerosol concentration. The sample port was then connected to each of the three diffusion batteries, in turn, and the number of aerosol particles penetrating the particular battery obtained. The penetrations g_3, g_4 and g_5 through the diffusion batteries (nos. 3, 4 and 5) were then calculated from the ratio of the number of condensation nuclei registered with and without a battery. An optimal fit of the Kth approximation of the size distribution $n^{(K)}(d)$ to the actual distribution $n(d)$ was then obtained

using diffusion battery data. The experimental diffusion battery penetration, g_j, is related to the theoretically calculated penetration probability, $P_j(d)$ by

$$g_j = \int_0^\infty P_j(d)\, n(d)\, d(d) \qquad (2)$$

where n(d) is the required aerosol size distribution.

The optimization calculation minimizes the difference between g_j as given by equation (1) and the approximation $g_j^{(K)}$ where

$$g_j^{(K)} = \int_0^\infty P_j(d)\, n^{(K)}(d)\, d(d)$$

The penetration probability of a particle passing through the diffusion battery is given by

$$P = \sum_{i=1}^{\infty} a_i\, e^{-b_i \mu} \qquad (3)$$

where μ = 2 WLD/FH for a rectangular plate diffusion battery

W = width of each rectangular plate (cm)

L = length of each rectangular plate (cm)

D = diffusion coefficient of the particle (cm^2/s)

F = volume flow rate through a single channel in the diffusion battery (cm^3/s)

2H = spacing between two plates (cm) (2H << W)

The penetration constants a_i and b_i for parallel plate diffusion batteries are:

$a_1 = 0.91035$, $a_2 = 0.5314$, $a_3 = 0.01529$, $a_4 = 0.0068$

$b_1 = 1.88517$, $b_2 = 21.4317$, $b_3 = 62.3166$, $b_4 = 124.5$

The dimensions of the diffusion batteries are given in Busigin, van der

Vooren and Phillips (Bu78).

At a sampling rate of 3 L/min, diffusion battery (D.B.) no. 3 removes 50% of the 0.03 μm particles, D.B. no. 4 removes 50% of the 0.08 μm particles and D.B. no. 5 removes 50% of the 0.2 μm particles. The theoretical fractional penetration through the three diffusion batteries vs. the diffusion coefficient is shown in Fig. 1.

The count median diameter, d, and the geometric standard deviation, σ_g, were calculated by using the experimental diffusion battery penetrations, g_j, as input for a computer program based on the optimization procedure described earlier. The derived mine aerosol size distributions are shown in Figs. 6-12 in Appendix C. The aerosol concentration records for each measurement day are shown in Figs. 13-20 in Appendix C.

For determination of the activity size distribution, the concentration of the radioactive species of interest is used instead of the aerosol concentration. The experimental method consists of drawing air through 0.8 μm pore size Millipore Type AA filters placed in magnetic filter holders at the exit ends of the diffusion batteries. An open face filter holder with a similar filter is used as a reference. Air is drawn simultaneously through the reference filter and the three diffusion batteries for ten minutes. The filters are then counted in portable scintillation counters according to a counting schedule based on optimization with respect to minimum uncertainty in measurement of each of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb. The fluctuations in flow rate and concentrations during sampling were taken as 5% each. Two samples per day could be obtained using this schedule of 10 minutes sampling and subsequent counting 2-4, 9-12, 85-95 and 240-250 minutes after sampling. An extra

count for the reference filter was obtained at 650-750 minutes for each sample in order to determine the concentration of ^{212}Bi.

For the diffusion battery measurements, the following equations were used to calculate the concentrations C(1), C(2), C(3) and C(4) for ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb, respectively.

$$\eta VC(1) = 0.146577\ I(1) - 0.135175\ I(2) + 0.039193\ I(3) - 0.02596\ I(4)$$

$$\eta VC(2) = -0.0167797\ I(1) + 0.009946\ I(2) + 0.022673\ I(3) - 0.017961\ I(4)$$

$$\eta VC(3) = -0.0072511\ I(1) + 0.035622\ I(2) - 0.017533\ I(3) + 0.012187\ I(4)$$

$$\eta VC(4) = -0.00001194I(1) + 0.0000433I(2) - 0.0001868\ I(3) + 0.005955I(4) \quad (4)$$

The concentration of ^{212}Bi was obtained from the equation:

$$\eta VC(5) = -0.00019\ I(1) + 0.00069\ I(2) - 0.00297\ I(3) + 0.09485\ I(4) - 0.01405\ I(5) \quad (5)$$

In eqns. (4) and (5), the I(j) are the counts obtained in the jth counting interval, and η and V are the counting efficiency and the sampling flow rate (L/min) respectively.

For the last two days of measurements, the sampling and counting schedules were varied in order to increase the number of samples obtained per day from two each to four each, for both the radon and thoron progeny. The activity size distribution for radon progeny could only be obtained in terms of the radon progeny Working Level, however. The scheme consisted of 5 minute sampling followed by 2-7 minute counting for radon progeny and 15 minute sampling followed by 330-345 minute counting for thoron progeny.

The radon progeny Working Levels were calculated using the equation:

$$RnWL = \frac{I(2\text{-}7)}{5 \times 5 \times 235\ \eta V} \qquad (6)$$

The thoron progeny Working Levels were calculated as:

$$TnWL = \frac{I\ (330\text{-}345)}{15 \times 15 \times 13\ \eta V} \qquad (7)$$

However, the first sample of the day was counted at 270-285 minutes after sampling in order to allow counting to be completed in the underground working period. Equation (7) was used to calculate the thoron progeny Working Level in this case, with I(330-345) replaced by I(270-285).

The concentration of ^{212}Pb was calculated from:

$$C_{^{212}Pb} = \frac{I\ (330\text{-}345)}{2.22 \times V \times 15 \times 15 \times \exp(-\lambda_{^{212}Pb} \times 337.5) \times \eta}$$

$$= \frac{I(330\text{-}345)}{345.78\ V\eta} \qquad (8)$$

For the first sample of the day, this concentration is given by:

$$C_{^{212}Pb} = \frac{I(270\text{-}285)}{369.14\ V\eta} \qquad (9)$$

The activity size distributions were determined from the calculated concentration penetration values for the diffusion batteries using the method outlined earlier. The data obtained from these measurements are listed in Tables 1 and 2 under the heading 'Previous' in the column for activity median diameters.

In order to determine whether the presence of the unattached fraction shifts the calculated activity size distribution (the shift can be viewed as the error in describing a bimodal distribution as a unimodal size distribution), unattached fraction values of 1%, 5% and 10% were used. The experimental diffusion battery data were re-evaluated by

subtracting 1%, 5% and 10% of the concentration of a radionuclide from its reference concentration (that determined from an open face filter) and calculating new diffusion battery penetration values for the attached fraction. Since the diffusion batteries had previously been shown to be capable of removing 100% of unattached fraction atoms (diffusion coefficient ~ 0.054 cm^2/s), no correction was necessary for the diffusion battery data (Fig. 1). The activity median diameter for each radionuclide of interest was then re-calculated based on the theoretical procedure described earlier in this section. The results of these calculations are listed in Tables 1 and 2 for the track and trackless mine, respectively. The previous values are also reported for convenient comparison. The blanks in some columns represent a situation where subtracting a specified unattached fraction from the reference resulted in penetration fractions of greater than unity, a physically impossible situation. The activity size distributions are plotted in Figs. 21-29 (Appendix C) for Po-218, Pb-214, Bi-214, Pb-212 and RnWL.

2.2 Unattached Fractions

Measurements of the unattached fractions of radon and thoron progeny were carried out using the wire screen method (Ge72). In this method, air is sampled simultaneously through two open face filter holders placed side by side, one containing the reference filter and the other containing a filter preceded by a wire screen (60 mesh per inch). The wire screen is separated from the filter by an O-ring to keep the atoms of radon and thoron progenies deposited on the filter from reaching the wire screen by recoil. The wire screen efficiency for collecting the

unattached atoms of radon and thoron progeny has experimentally been found to be 77% at a linear air velocity of 11.5 cm/sec (Ge72). The efficiency of the wire screen can be calculated theoretically from Thomas and Hinchliffe's equation (Th72):

$$E = 1 - (0.82\ e^{-0.233h} + 0.18\ e^{-16.7h}) \qquad (10)$$

where $h = 100\ M^2\ d\ D/V$

E = collection efficiency

M = mesh size (mesh/cm)

d = wire diameter (cm)

D = diffusion coefficient of the atom under investigation (cm^2/s)

V = linear air velocity (cm/s)

However, the diffusion coefficients of radon and thoron progeny are not accurately known and can vary significantly with ventilation rate (Ko76), charge state (Bi71), relative humidity (Ra79) and the nature of the gaseous environment (Bu81). The experimental efficiency of 77% for 11.5 cm/s air velocity was therefore adopted in equation (10) in order to find the corresponding value of the product Vh. This value was later used to calculate the collection efficiency corresponding to the measured air velocity in each case. The theoretical wire screen efficiency as a function of face velocity for a diffusion coefficient 0.054 cm^2/s is plotted in Fig. 2.

The reference filter and the backup filter for the wire screen were counted in pre-calibrated Trimet ZnS alpha counters (Trimet Instruments Ltd. Model 372A) according to a pre-determined counting schedule, optimized in order to minimize the overall uncertainty in the measurements.

The unattached fraction was calculated from the differences in activities counted on the two filters and the appropriate wire screen efficiency. Direct counting of the wire screen was used in a few instances. In these cases, the exact counting efficiency of the wire screen is unknown because of the complex self-absorbing geometry of the screen.

The sampling and counting schedule was determined by a mathematical procedure similar to that used by Busigin and Phillips (Bu80) for 3-count radon progeny determination and by Khan, Busigin and Phillips (Kh82) for 5-count radon and thoron progeny determination. A ten minute sampling period was adopted for mixtures of radon and thoron progeny (Kh82). A counting schedule was determined for four counting intervals for measurement of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb. Fluctuations in flow rate and concentration of individual species were each taken as 5%. For development of the counting scheme, the unattached counts of ^{218}Po, ^{214}Pb, ^{214}Bi, ^{212}Pb and ^{212}Bi were taken to be 5% of typical levels (100, 60, 40 and 2 and 1 pCi/L) found in uranium mines. The most suitable counting intervals were found to be 2-5, 9-25, 40-70 and 360-460 minutes after sampling. Within the allowed underground working period of about 5.5 hours, two samples per day could be obtained using this counting scheme. One more sample could be obtained by modifying the scheme a little in such a way that the uncertainties associated with the measurement were not affected appreciably. The counting intervals appropriate for this extra sample were determined to be 2-5, 9-25, 30-60, 360-460 minutes after sampling. Only the third counting interval was shifted (by ten minutes).

Equations for determining the concentrations of radon and thoron progeny from the counts obtained in the four counting intervals are given

below. I(1), I(2), I(3), I(4) represent the counts obtained in the first, second, third and fourth counting intervals respectively. C(1), C(2), C(3) and C(4) denote the concentrations of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb, respectively. V is the pump flow rate in L/min and η is the efficiency of the counter.

For the counting scheme of 2-5, 9-25, 40-70, 360-460, the following equations apply:

$$V\eta C(1) = 0.095346\ I(1) - 0.036333\ I(2) + 0.015622\ I(3) - 0.001732\ I(4)$$
$$V\eta C(2) = -0.010716\ I(1) + 0.000852\ I(2) + 0.004594\ I(3) - 0.000905\ I(4)$$
$$V\eta C(3) = -0.001851\ I(1) + 0.00935\ I(2) - 0.005512\ I(3) + 0.000696\ I(4)$$
$$V\eta C(4) = -0.0000002I(1) + 0.0000006I(2) - 0.0000099I(3) + 0.00065\ I(4) \quad (11)$$

For the counting scheme of 2-5, 9-25, 30-60, 360-460, the equations are:

$$V\eta C(1) = 0.097002\ I(1) - 0.040587\ I(2) + 0.016187\ I(3) - 0.001254\ I(4)$$
$$V\eta C(2) = -0.010229\ I(1) - 0.000398\ I(2) + 0.00476\ I(3) - 0.000764\ I(4)$$
$$V\eta C(3) = -0.002435\ I(1) + 0.010851\ I(2) - 0.005711\ I(3) + 0.000527\ I(4)$$
$$V\eta C(4) = -0.0000003I(1) + 0.0000008\ I(2) - 0.000001\ I(3) + 0.00065\ I(4) \quad (12)$$

The concentrations were calculated for both the reference filter and the back-up filter for the wire screen using the appropriate set of equations. The unattached fraction, f_u, was then calculated as

$$f_u = \frac{C_u}{C_{ref}} = \frac{C_{ref} - C_{WS}}{EC_{ref}} \quad (13)$$

where C_u = concentration of the unattached species (pCi/L)

C_{ref} = concentration of the species collected on the reference filter (pCi/L)

C_{WS} = concentration collected on the filter behind the wire screen (pCi/L)

E = efficiency of the wire screen for collecting the unattached species.

The measurement schedule for unattached fractions was varied for the last two days of measurement because of the high levels of uncertainty associated with measurement of the smaller unattached fractions in the high aerosol environment of the diesel-operated mine. Measurement of individual radon decay products was, therefore, abandoned for the last two days, and radon Working Levels were measured instead. In addition, in order to obtain more samples per day, the sampling period was reduced to 5 minutes and counting was carried out 2-7 minutes after sampling. This counting scheme was based on a separate optimization carried out for rapid Working Level determination with minimum uncertainty. Based on a similar optimization for thoron Working Level, sampling for unattached thoron progeny was carried out over 15 minutes and the filters were counted 330-360 minutes after sampling. The uncertainties associated with radon and thoron Working Level determination by this method were 6.8% and 9% respectively. This method made it possible to obtain four samples each (per day) of radon and thoron progeny. However, only the total unattached radon progeny could be calculated, not the individual decay products. The concentration of ^{212}Pb was calculated for 15 minute sampling and 30 minute counting from:

$$C_{^{212}Pb} = \frac{I\ (330\text{-}360)}{2.22 \times V \times 15 \times \exp(-\lambda_{^{212}Pb} \times 345) \times \eta \times 30} \qquad (14)$$

where I (330-360) = counts obtained in 330-360 minutes interval after sampling

V = pump flow rate (L/min)

η = counting efficiency

$\lambda_{^{212}Pb}$ = disintegration constant of ^{212}Pb (min^{-1})

The radon and thoron Working Levels were calculated using the following equations:

$$RnWL = \frac{I(2\text{-}7)}{5 \times 5 \times 235\ \eta V} \qquad (15)$$

for 5 minute sampling and 5 minute counting 2-7 minutes after sampling, and

$$TnWL = \frac{I(330\text{-}360)}{15 \times 30 \times 13\ \eta V} \qquad (16)$$

for 15 minute sampling and 30 minute counting 330-360 minutes after sampling. For the first sample of the day, however, thoron progeny activity was counted at 270-300 minutes after sampling in order to allow counting within the underground working time. Equation (16) was also used for calculating the TnWL in this case with the activity I(330-360) replaced by I(270-300). The concentration of ^{212}Pb is given in this case by

$$C_{^{212}Pb} = \frac{I\ (270\text{-}300)}{732.3\ V\eta} \qquad (17)$$

The unattached fractions were calculated from equation (13).

The results of these measurements are reported in Tables 3 and 4. Detailed unattached fraction results are listed in Tables 5 and 6. Statistical means with best estimates of standard deviations for both

track and trackless mines are given in Table 7.

The unattached fractions for mixtures of Po-218, Pb-214, Bi-214 and Pb-212 in the four counting intervals were calculated from the equation:

$$f = \frac{I_{ref} - I_B}{E\, I_{ref}} \quad , \tag{18}$$

where I_{ref} represents the gross alpha counts on the reference filter, I_B refers to the gross alpha counts on the back-up filter behind the wire screen and E is the wire screen efficiency for removing the unattached atoms. The gross alpha counts on the reference filter were normalized in each case with respect to pump flowrate and counterefficiency for the corresponding back up filter.

The results are listed in Tables 8a and 8b for the track and trackless mine, respectively. The mean unattached fraction along with the best estimate of the standard deviation (σ_{n-1}) is also shown for each mine. The detailed schedules for measurements are given in Appendix D. The measured concentrations and the radon and thoron Working Levels are summarized in Tables 13-15 in Appendix B. Tables 16 and 17 in Appendix B summarize the unattached fractions, the activity size distributions and the aerosol size distributions.

2.3 Wire Screen Counts

Because of lack of knowledge of the exact geometric efficiency of the counter with respect to wire screen only three measurements involving direct counting of the wire screen were attempted. The measurements were carried out on Feb 4, 5 and 6. The alpha counts obtained and the concentrations calculated from these measurements are shown in Tables 3 and

4, respectively. Since the statistical errors are large due to the small number of counts obtained in each case, the data can only be used to provide an estimate of unattached fractions.

Unattached fractions were calculated for mixtures of radon and thoron progeny (Table 9) using the equation:

$$f_{ws} = \frac{I_{ws}}{E_G EI_{ref}} \quad , \tag{19}$$

where I_{ws} is the gross alpha activity counted on the wire screen and E_G = 0.5 is the assumed geometric counting efficiency for the screen in accordance with George (Ge72).

2.4 Theoretical Determination of Unattached Fraction.

The attachment rate, λ_s, of radon and thoron progeny atoms to aerosols is the single most important parameter in the theoretical calculation of unattached fractions. The rate of attachment can be expressed as:

$$\lambda_s = \beta Z \quad , \tag{20}$$

where β = attachment coefficient (cm^3/s)

Z = aerosol concentration ($\#/cm^3$)

The attachment rate, λ_s, may then be substituted into appropriate radioactive decay equations, discussed later in this section, in order to allow calculation of the unattached fraction of radon and thoron progeny. The validity of the theoretical calculation, however, depends mainly on the accuracy of the value of attachment coefficient, β. Many different equations for estimating the attachment coefficient have been suggested. However, the most acceptable version to date can be summarized as follows:

For small particles (Knudsen number, $Kn = \ell/d_p > 1$; particle

diameter << 0.065 μm)

$$\beta = \frac{\pi}{4} d_p^2 \bar{V} \quad \text{(kinetic theory)} , \tag{21}$$

where d_p is the particle diameter, V is the theoretical diffusion velocity of the unattached atoms, and ℓ is the mean free path of gas molecules in the air (~ 0.065 μm under standard conditions).

For large particles (Knudsen number <1; particle diameter >> 0.065 μm)

$$\beta = 2 \pi d_p D \quad \text{(diffusion theory)} , \tag{22}$$

where D is the diffusion coefficient of the unattached atoms.

However, since most of the aerosols in these measurements were within the range 0.05-0.08 μm, it is more appropriate to use an interpolation formula for the intermediate range as suggested by Mohnen (Mo67):

$$\beta = \frac{\pi \bar{V} d_p^2 \left(\frac{d_p}{2} + \ell\right) D}{4 D \left(\frac{d_p}{2} + \ell\right) + \bar{V} \frac{d_p^2}{4}} \quad \text{(hybrid theory)} , \tag{23}$$

The diffusion coefficient D was taken to be the normally accepted value of 0.054 cm^2/s; a value of D = 0.02 cm^2/s was also used for one set of calculations to simulate the effects of heavy clustering, etc. The attachment coefficient β was calculated from eqn. (23). The formulation and solution of unattached fraction equations is discussed below.

Unattached Po-218 is formed from the decay of radon and thereafter either becomes attached to aerosols at a rate, λ_s, or decays while unattached. Pb-214 can be formed either from the decay of unattached Po-218 or from the decay of the fraction of Po-218 which becomes detached on recoil. Unattached Pb-214 is removed either by attachment to aerosols or

by radioactive decay leading to formation of unattached Bi-214. A fraction of the Pb-214 can also become unattached on recoil but no experimental evidence has been found to support this possibility (Ra69; Mc72). The recoil formation term of Bi-214 is therefore generally taken to be zero.

The following equations describe the net formation rate of the atoms of unattached Po-218, Pb-214 and Bi-214, whose number concentrations are

$$\frac{dN_{2_f}}{dt} = \lambda_1 N_1 - (\lambda_s + \lambda_2) N_{2_f} \tag{24}$$

$$\frac{dN_{3_f}}{dt} = \lambda_2 N_{2_f} + \alpha\, \lambda_2 (N_2 - N_{2_f}) - (\lambda_s + \lambda_3) N_{3_f} \tag{25}$$

$$\frac{dN_{4_f}}{dt} = \lambda_3 N_{3_f} - (\lambda_s + \lambda_4) N_{4_f} \tag{26}$$

The subscripts 1, 2, 3 and 4 refer to radon, Po-218, Pb-214 and Bi-214 respectively. λ_i's are the radioactive decay constants, α is the recoil fraction of the Po-218 which becomes unattached Pb-214 upon decay, and λ_s is the rate of attachment of atoms to aerosols, given by eqn. (20).

The solutions of eqns. (24)-(26) are given by:

$$N_{2_f} = \frac{\lambda_1 N_1}{\lambda_2 + \lambda_s} \left(1 - e^{-(\lambda_2 + \lambda_s)t}\right) \tag{27}$$

$$N_{3_f} = \frac{\lambda_1 N_1}{\lambda_3 + \lambda_s} \left[\frac{\lambda_2 (1 - \alpha)}{\lambda_2 + \lambda_s} + \alpha\right] \left(1 - e^{-(\lambda_3 + \lambda_s)t}\right)$$

$$+ \frac{\lambda_1 N_1 \lambda_2 (1 - \alpha)}{(\lambda_2 + \lambda_s)(\lambda_3 - \lambda_2)} \left(e^{-(\lambda_3 + \lambda_s)t} - e^{-(\lambda_2 + \lambda_s)t}\right)$$

$$+ \frac{\lambda_1 N_1 \alpha}{\lambda_3 - \lambda_2 + \lambda_s} \left(e^{-(\lambda_3 + \lambda_s)t} - e^{-\lambda_2 t}\right) \tag{28}$$

$$N_{4_f} = \frac{\lambda_1 N_1 \lambda_3}{(\lambda_4+\lambda_s)(\lambda_3+\lambda_s)} \left[\frac{\lambda_2(1-\alpha)}{\lambda_2+\lambda_s} + \alpha\right](1 - e^{-(\lambda_4+\lambda_s)t})$$

$$+ \frac{\lambda_1 N_1 \lambda_3}{(\lambda_4-\lambda_3)} \left[\frac{\alpha}{\lambda_3-\lambda_2+\lambda_s} + \frac{\lambda_2(1-\alpha)}{(\lambda_2+\lambda_s)(\lambda_3-\lambda_2)} - \frac{\lambda_2(1-\alpha)}{(\lambda_2+\lambda_s)(\lambda_s+\lambda_3)}\right.$$

$$\left. - \frac{\alpha}{\lambda_3+\lambda_s}\right](e^{-(\lambda_3+\lambda_s)t}) - e^{-(\lambda_4+\lambda_s)t}) - \frac{\lambda_1 N_1 \lambda_2 \lambda_3 (1-\alpha)}{(\lambda_2+\lambda_s)(\lambda_3-\lambda_2)(\lambda_4-\lambda_2)}$$

$$e^{-(\lambda_2+\lambda_s)t} - e^{-(\lambda_4+\lambda_s)t}) - \frac{\lambda_1 N_1 \lambda_3 \alpha (e^{-\lambda_2 t} - e^{-(\lambda_4+\lambda_s)t})}{(\lambda_s+\lambda_4-\lambda_2)(\lambda_3-\lambda_2+\lambda_s)} \qquad (29)$$

The total numbers of Po-218, Pb-214 and Bi-214 atoms (N_2, N_3 and N_4, respectively) are given by:

$$N_2 = \frac{\lambda_1 N_1}{\lambda_2}(1 - e^{-\lambda_2 t}) \qquad (30)$$

$$N_3 = \frac{\lambda_1 N_1 \lambda_2}{\lambda_3(\lambda_2-\lambda_3)}\left[(1 - e^{-\lambda_3 t}) - \frac{\lambda_3}{\lambda_2}(1 - e^{-\lambda_2 t})\right] \qquad (31)$$

$$N_4 = \frac{\lambda_1 N_1}{\lambda_2-\lambda_3}\left[-\frac{\lambda_3}{\lambda_4}(1 - e^{\lambda_4 t}) + \frac{\lambda_2}{\lambda_4}(1 - e^{-\lambda_4 t})\right.$$

$$\left. - \frac{\lambda_2}{\lambda_4-\lambda_3}(e^{-\lambda_3 t} - e^{-\lambda_4 t}) + \frac{\lambda_3}{\lambda_4-\lambda_2}(e^{-\lambda_2 t} - e^{-\lambda_4 t})\right] \qquad (32)$$

The unattached fractions of Po-218, Pb-214 and Bi-214 (f_2, f_3 and f_4, respectively) can be calculated as:

$$f_2 = \frac{N_{2_f}}{N_2} \qquad (33)$$

$$f_3 = \frac{N_{3_f}}{N_3} \qquad (34)$$

$$f_4 = \frac{N_{4f}}{N_4} \qquad (35)$$

The results of these calculations based on the aerosol size distribution data in Table 10 are given in Tables 11a and 11 b. A value of V = 1.38 x 10^4 cm/s was used and the recoil fraction α was taken to be 0.81. The effective time, t, in the equations was taken as 5, 10, 20, 40, 60 minutes, to simulate a range of residence times for the air in an operating mine. Tables 11a and 11b are based on a diffusion coefficient of 0.054 cm^2/s for the unattached atoms. Table 12 shows results for an additional value of D = 0.02 cm^2/s for an effective air residence time of 20 min. All results are discussed in Section 3.

3.0 DISCUSSION OF RESULTS

3.1 Aerosol and Activity Size Distribution

The aerosol and activity size distributions in Tables 1, 2 and 10 are similar, the particle size in the track mine being slightly smaller than the particle size in the trackless mine. The results of the calculations for unattached fractions in Tables 1 and 2 show that there is a slight shift in the activity median diameter towards a larger value as the unattached fraction increases. The difference between the previous activity median diameter values and values after correcting for 10% unattached fraction ranges from 10 to 20%.

The aerosol size distribution may have been influenced by the cut-off diameter of the condensation nuclei counter used for these measurements. The cut-off diameter of the portable Environment One (Model Rich 100) condensation nuclei counter used is 0.0025 μm. The size distribution

determined covers the range ~ 0.0009 μm - 0.027 μm for a count median diameter of 0.05 μm. A significant error may therefore result from the condensation nuclei counter's inability to register particles in the reference count below 0.0025 μm. This inability may even account for the small differences in aerosol and activity median diameter because the activity median diameter determination is not subject to any limits on the size of the smallest detectable particle. The error due to using a single count median diameter instead of a complete size distribution is discussed in greater detail in Section 3.4.

3.2 Unattached Fraction

The unattached fraction results listed in Tables 5 and 6 exhibit a large scatter. Table 7 summarizes the results in terms of mean values of the unattached fractions. The mean values indicate that, in general, the unattached fractions in the track mine are higher than those in the trackless mine. This result is not surprising because the aerosol concentrations in the track mine were much lower than the aerosol concentrations in the trackless mine.

The unattached fraction values calculated from the gross alpha counts in the four counting intervals, listed in Tables 8a and 8b, exhibit less scatter than individual radon/thoron progeny unattached fractions, and have standard deviations ranging from 0.05-0.10 compared to 0.07-0.30 for the individual concentration data in Table 7. This difference is further studied from a statistical point of view. The error in the method of determining unattached fractions, namely, counting a reference filter and a backup filter, was evaluated in terms of the probability of the

gross alpha counts (or concentrations) on the back up filter being greater than those on the reference filter. Taking μ as the difference between means for the reference filter and the backup filter data and σ^2 as the sum of variances for the two sets of data, the normalized standard variate z was determined as

$$z = \frac{x - \mu}{\sigma} \tag{36}$$

where x is the number of counts or the concentration in pCi/L.

For gross alpha counts, counts in the range experienced, namely, 500-6000 counts, were used to evaluate errors in determining hypothetical 1%, 2%, 5%, 10% and 20% unattached fractions. The probability 1 - F(z) for the backup filter counts to be greater than the reference filter counts was determined from standard statistical tables. The results of this statistical analysis are listed in Table 8c and plotted in Fig. 3. The same procedure was repeated for individual concentrations of Po-218, Pb-214, Bi-214 and Pb-212, equal to 50, 30, 20 and 1 pCi/L respectively. These results are plotted in Fig. 4.

Comparison of Figs. 3 and 4 illustrates the large errors associated with the determination of the unattached fraction of individual radon/thoron progeny relative to the errors associated with determination of the unattached fraction from gross alpha counts. The actual mine data range for the gross alpha counts was ~ 2000 - 50,000. It can be observed from Fig. 3 that the probability of the back up filter counts being greater than the reference filter counts is <5% for counts >2000 for unattached fractions of 5% or more. Even for unattached fractions as low as 2%, the probability of the back up filter counts being greater than the

reference filter counts is <15% for 6000 or more counts, a range in which most of the mine data fall. Thus for unattached fraction determination based on gross alpha activity, the method of reference and backup filter counting is reasonably accurate. In contrast, the accuracy of the method when applied to individual concentrations becomes unacceptable due to the large uncertainties associated with concentration determination, as indicated by the middle row in Table 7.

The accuracy of the unattached fraction of Pb-212 is the same whether calculated from gross alpha activity or individual concentrations, because in the counting interval 450-460 min after sampling there is almost no contribution from the radon progeny and the activity is almost entirely due to Pb-212. The probability of the backup filter concentration of Pb-212 being larger than its reference filter concentration is mainly due to the low activity (1 pCi/L) and consequently the small difference between the backup and the reference filter concentrations. However the precision of measurement of Pb-212 itself is much better than for the radon progeny (Table 7). The precision of measuring Pb-214 is close to that for Pb-212 and, as indicated in Fig. 4, Pb-214 is subject to the least error of the radon progeny in determining its unattached fraction.

In order to examine the unattached fraction method based on the difference between backup and reference filter concentrations, the mine data were subjected to a paired t-test. The null-hypothesis that the difference between the backup filter-mean and reference filter-mean concentrations is indistinguishable from zero was tested for Po-18, Pb-214, Bi-214 and Pb-212 for track and trackless mines separately. The results

are summarized in Table 8d. It can be seen from Table 8d that the null-hypothesis described above is rejected at a significance level of 0.05 for all the nuclides of interest in both mines. At 0.01 level of significance the hypothesis is rejected in all cases except that of Po-218 in the track mine, because of the exceptionally high uncertainty associated with the determination of Po-218 (Table 7). Two sample calculations for Table 8d are provided in Appendix A.

3.3 Wire Screen Counting

Only three wire screen counts were made during the measurement period. In processing these data, the geometric efficiency for wire screen counting was assumed to be 0.5 in the absence of specific information. The geometry of the wire screens is complicated with wires running under and over each other. In order to find another estimate of unattached fractions, wire screens were counted on Feb. 4, 5 and 6 for sample #2. From Table 3 it can be seen that the wire screen counts are very low, and consequently have large statistical errors. Table 4 data for Feb. 4, 5 and 6 show that the calculated concentrations are very small (-0.01 to 0.92 pCi/L). The negative concentration result is a manifestation of the level of statistical uncertainty associated with a calculation based on individual matrix elements each subject to large uncertainties. In view of the discussion in Section 3.2 on the statistical error associated with determination of the unattached fractions based on concentrations, the small concentrations calculated in the wire screen case may be expected to yield values for the unattached fractions which are subject to very large and unacceptable uncertainties. However, if the

gross alpha activity method is used, the wire screen unattached fractions are found to range from 0.01 to 0.05, assuming the geometric counting efficiency of the screen to be 0.50.

In order to examine this question further, a detailed statistical analysis was carried out to compare the overall relative standard deviations in the wire screen counting method and the method based on the difference between reference and backup filter. These two methods were examined for unattached fractions based on both gross alpha counts and individual radionuclide concentrations.

For the gross alpha counts method, the effects of flow fluctuations and counting statistics were taken into account. For wire screen counting, the unattached fraction is related to the counts by:

$$f_{ws} \propto \frac{I_{ws}}{I_{Ref}} \tag{37}$$

where I_{ws} and I_{Ref} represent the counts from the wire screen and the reference filter, respectively. The overall relative standard deviation of f_{ws} is given by:

$$RSD_{ws} = \sqrt{(RS_{ws})^2 + (RS_{Ref})^2} \tag{38}$$

where $$RS_{ws} = \sqrt{\frac{1}{I_{ws}} + \left(\frac{\Delta V}{V}\right)^2} \tag{39}$$

$$RS_{Ref} = \sqrt{\frac{1}{I_{Ref}} + \left(\frac{\Delta V}{V}\right)^2} \tag{40}$$

The first term in equations (39) and (40) represents the square of the counting uncertainty expressed as $\sqrt{n}/n$ for n counts. The fluctuations in flowrate are described by the term $\Delta V/V$, which was taken as 0.05 and

0.10 in order to explore the effect of flow change during the measurements.

For the reference minus backup filter activity method, the unattached fraction relationship is

$$f_{Ref-Buf} \propto \frac{I_{Ref} - I_{Buf}}{I_{Ref}} \tag{41}$$

or $$f_{Ref-Buf} \propto 1 - \frac{I_{Buf}}{I_{Ref}} \tag{42}$$

The overall relative standard deviation can be expressed as:

$$RSD_{Ref-Buf} = \sqrt{(RS_{Buf})^2 + (RS_{Ref})^2} \tag{43}$$

where RS_{Ref} is given by eqn. (40) and RS_{Buf} is given as:

$$RS_{Buf} = \sqrt{\frac{1}{I_{Buf}} + \left(\frac{\Delta V}{V}\right)^2} \tag{44}$$

Calculations were carried out for counts obtained in each of the four counting intervals 2-5, 9-25, 40-70 and 360-460 minutes after sampling. The results of these calculations are given in Table 9a.

A similar procedure was followed for the concentration-based method except that RS_{ws}, RS_{Ref} and RS_{Buf} for each radionuclide were calculated in a statistical procedure for calculating uncertainties in concentration measurements (Kh82). Fluctuations in concentration during sampling were neglected and RS_{ws}, RS_{Ref} and RS_{Buf} were calculated for 5% and 10% fluctuations in flow during sampling using the individual concentration values from the data listed in Table 4. The final results based on the calculated RS_{ws}, RS_{Ref} and RS_{Buf} values in eqns. (38) and (43), respectively,

are given in Table 9b.

Tables 9a and 9b do not take into account any uncertainties which may be associated with calibration of the alpha counters, the determination of the collection efficiency of the wire screen, or determination of its geometric counting efficiency. For the sake of completeness, the following procedure was adopted to include these uncertainties in the calculations.

Table 9c lists the calibration data for the alpha counters and suggests that the relative standard deviation for counting efficiency, $RS_{E(count)}$, can be taken as 0.02 for all counters. The wire screen counting efficiency uncertainty can be taken as 10% (RS_K = 0.1) in view of the limited data available in the literature. The collection efficiency of wire screens is determined from eqn. (10). The last term on the right hand side of the equation is negligibly small for the experimental conditions used, and may be neglected. Applicàtion of the law of propagation of uncertainties to this equation then gives

$$S_{E(coll.)} = 2.87 \frac{\Delta V}{V^2} e^{-3.5/V} \qquad (45)$$

where V is the flowrate in litres per minute. (The linear air velocity in eqn. (10) is replaced here by the corresponding volumetric flow rate.) Equation (45) can be re-written as:

$$RS_{E(coll.)} = \frac{2.87}{V} e^{-3.5/V} \left(\frac{\Delta V}{V}\right) E \qquad (46)$$

For $\Delta V/V = 0.05$, and values of E and V from Table 5, $RS_{E(coll.)}$ is found from eqn. (46) to be ~ 0.02. A value of 0.03 was therefore chosen for the calculations.

The new equations for calculating the overall relative standard

deviation can be written as

$$RSD_{Ref-Buf} = \sqrt{(RS_{Buf})^2 + (RS_{Ref})^2 + (RS_{E(coll.)})^2 + 2\,(RS_{E(count)})^2} \quad (47)$$

$$RSD_{WS} = \sqrt{(RS_{WS})^2 + (RS_{Ref})^2 + (RS_{K})^2 + (RS_{E(coll.)})^2 + 2(RS_{E(count)})^2} \quad (48)$$

The revised overall standard deviations for gross alpha counts based on eqns. (47) and (48) are listed in Table 9d.

It can be seen from Tables 9a and 9b that the relative standard deviation for the reference minus backup filter activity method is less than that for the wire screen counting method in each case. The overall relative standard deviations are much less for the gross alpha count method than for the concentration method, a conclusion also reached in the previous section. In both cases, an increase in the flowrate fluctuation from 0.05 to 0.10 results in a larger effect on the precision of the reference minus backup filter activity method than on the precision of the wire screen counting method. This conclusion is expected because of the calculation of a difference in the former method.

Table 9d reflects a small increase in the overall relative standard deviation caused by inclusion of additional uncertainties for alpha counter calibration, wire screen collection efficiency and the geometric counting efficiency of the wire screen. The conclusion that the difference (reference - backup) method for gross counts is more precise than the wire screen counting method for gross counts remains unchanged. Further insight into the two methods may be obtained by calculating an activity balance in which the sum of the activities collected on the wire

screen and on the back-up filter is compared with the activity collected on the reference filter. The results are listed in Table 9e. The wire screen counts are corrected for collection efficiency based on Table 5, and incorporate a wire screen counting efficiency of 0.5 (Ge72). The considerable and unknown uncertainties in both these corrections are not reflected in Table 9e in N_{WS}, which is based on counting statistics alone. The reference filter in general collected more activity than the sum of the wire screen and back-up filter activities.

A systematic error in pump flow rates is possible but not likely given daily calibration and visual observation of flowrate during actual sampling and the fact that the flowrates of the pumps are feed-back controlled during operation. Further, careful examination of the nature of the sealing surfaces in the samplers (Fig. 4a) suggests that leaks are quite unlikely to be present. Spatial variation of the concentrations of radon progeny during sampling is also possible but not likely to be the cause since the difference is systematic. Uncertainties in the screen collection efficiency and in the screen counting efficiency provide possible explanations. Deposition on the screen is likely to be uneven. If deposition is high in the crevice between the overlapping wires of the screen, low activity will be reported since the overlying screen wire will absorb most of the alphas originating from the crevice. (An error in this direction is required to account for the observed differences in Table 9e). For this effect to explain the results, the screen counting efficiency, assumed to be 0.5, would have to be less by a factor ~ 2. Although there is no evidence for low screen counting efficiencies caused by screen wire shielding of localized deposits in crevices under overlying

wires, it remains a possibility. This explanation would also help reconcile the unattached fractions measured by counting the wire screen with those measured by counting the back-up and reference filters. Unfortunately, however, no firm conclusion as to the source of the activity balance deficit can be reached. Careful detailed work on this question is clearly warranted.

Notwithstanding the greater uncertainties associated with the concentration unattached fractions as compared to the gross alpha unattached fractions, the former are plotted with results of other workers (who did not determine gross alpha unattached fractions) in Figs. 4b and 4c. The results of the present work (determined by the backup-reference filter method) fall into the same general range as the results from the literature.

3.4 Theoretical Determination of the Unattached Fractions

Procedures for the determination of unattached fractions using a mathematical model for attachment and the experimentally obtained aerosol concentration and diameter were described in Section 2.4. Mathematical models for attachment have been subject to research for the past two decades and require some discussion before a particular model is singled out as the most appropriate one for calculation of unattached fractions.

The three commonly used attachment theories were described in Section 2.4, namely, the kinetic theory for $Kn > 1$, the diffusion theory for $Kn < 1$ and the hybrid theory for the transition region of $Kn \sim 1$. These theories are plotted in Fig. 5. A mathematical model originally presented by Fuchs (Fu64) is also plotted in Fig. 5 for comparison. Fuchs' model takes into account the individual particle sizes and dif-

fusion coefficients for both the radon progeny atom and the aerosol. This model predicts much lower attachment coefficients than the three other theories mentioned earlier. The difference cannot be explained and therefore it cannot be concluded whether Fuchs' mathematical model describes the attachment process correctly. The experimental data of Porstendorfer and Mercer (Po78) seem to confirm the validity of the kinetic theory of attachment in the particle size range 0.009-0.03 μm. Further experiments by Porstendorfer et al. (Po79) in the larger particle size range of 0.05-2.5 μm seem to agree with the diffusion theory of attachment. However, the kinetic theory has been found to be valid by many researchers in the particle size ranges 0.02-0.5 (Ra68), 0.6-2.65 (Kr79) and 1-5 μm (Ho82). The hybrid theory, first proposed by Mohnen (Mo67), seems to represent the attachment process in the entire size region 0.01-10 μm reasonably well because, as seen in Fig. 5, the attachment coefficients predicted by it are approximately equal to the kinetic theory-based attachment coefficients for particles <0.1 μm diameter and equal to the diffusion theory-based attachment coefficients for particles >2 μm diameter. The region between 0.1 and 2 μm also seems to be better represented by the hybrid theory than the kinetic or the diffusion theory. The hybrid theory was, in fact, aimed at predicting the attachment coefficients in the transition range, which is not satisfactorily described by either the kinetic or the diffusion theory. Unfortunately, the intermediate range (0.1-2 μm) has not been subjected to much experimental investigation. Porstendörfer's experiments (Po68) in the 0.2-4 μm diameter range are in agreement with the hybrid theory with the condition that the particle size is much greater than the particle mean free path. More

experimental evidence is required to confirm the validity of the hybrid theory. However, in the size range <0.1 μm it is safe to use either the kinetic theory or the hybrid theory because they predict approximately the same attachment coefficients in this size range.

The results of theoretical unattached fraction calculations listed in Tables 11a and 11b suggest that the age of air, or the effective time T, is an important parameter, especially in predicting the unattached fractions of Pb-214 and Bi-214. Since mine air may be a mixture of relatively young and old air, it is difficult to assign a number to the age of air at the time of the aerosol size and concentration measurement. An "average" age of the air can be estimated from the disequilibrium ratios of the radon progeny concentrations. Generally the age of the air in this series of measurements was found to be 20-50 minutes. It can be seen from Tables 11a and 11b that the unattached fractions of Pb-214 and Bi-214 become extremely small for air more than 20 minutes old. The notion of a single age of the air is clearly an oversimplification, and may be expected to lead to error in calculating the unattached fractions of particular progeny.

Representation of the entire aerosol size distribution by a single count median diameter is also likely to lead to errors. A detailed analysis of the unattached fraction determination was therefore undertaken by dividing the size spectrum of the aerosol into many strips, calculating the unattached fraction in each strip and then determining the overall unattached fraction from a weighted sum. The results of these calculations are shown in Table 11c, based on 21 strips in the size spectrum.

The theoretical unattached fractions calculated for the track mine

(Jan 30 - Feb 1 results) are higher than those in the trackless mine (Feb 4 - Feb 8 results), as previously observed in summary of the experimentally determined unattached fractions.

Finally, two different diffusion coefficients (0.054 cm^2/s and 0.02 cm^2/sec) were used for the calculation listed in Table 12 in order to determine the sensitivity of the calculated values to the value of the diffusion coefficient. The results suggest that the unattached fractions are essentially insensitive to the value of the diffusion coefficient within the range examined.

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TABLE 1

Activity Size Distributions
(calculated for unattached fractions (u.fn.) assumed as shown)

Track Mine:

Dated	Time	Species	Activity mean diameter (in μm) (GSD)			
			Previous	1% u.fn.	5% u.fn.	10% u.fn.
Jan 29	9.00	Pb-212	0.065 (2.690)	0.066 (2.475)	0.071 (2.449)	0.077 (2.464)
	9.15	Pb-212	0.064 (2.425)	0.065 (2.564)	0.070 (2.667)	0.079 (2.645)
Jan 30	8.45	Po-218	0.053 (2.209)	0.054 (2.074)	0.057 (1.978)	0.061 (1.650)
	8.45	Pb-214	0.047 (1.587)	0.047 (1.528)	0.049 (1.664)	0.054 (1.438)
	8.45	Bi-214	0.043 (2.427)	0.045 (2.262)	0.048 (2.336)	0.052 (2.025)
	8.45	Pb-212	0.057 (2.296)	0.059 (2.245)	0.063 (2.169)	0.068 (1.853)
	9.00	Po-218	0.063 (2.619)	0.064 (2.640)	0.071 (2.789)	0.080 (2.680)
	9.00	Pb-214	0.056 (1.511)	0.056 (1.651)	0.059 (1.365)	0.063 (1.432)
	9.00	Bi-214	0.059 (1.344)	0.059 (1.470)	0.063 (1.651)	0.067 (1.354)
	9.00	Pb-212	0.072 (2.474)	0.073 (2.408)	0.077 (1.963)	0.083 (1.789)
Jan 31	8.55	Pb-214	0.054 (2.158)	0.055 (2.062)	0.058 (1.856)	0.063 (1.579)
	8.55	Bi-214	0.057 (2.403)	0.058 (2.583)	0.063 (2.535)	0.068 (2.446)
	8.55	Pb-212	0.082 (2.550)	0.082 (2.617)	0.092 (2.713)	0.105 (2.524)
	9.10	Pb-214	0.044 (2.471)	0.044 (2.438)	0.047 (2.264)	0.051 (1.931)
	9.10	Bi-214	0.060 (2.191)	0.061 (2.160)	0.065 (1.872)	0.070 (1.573)
	9.10	Pb-212	0.100 (1.749)	0.101 (1.600)	0.109 (1.458)	-
Feb 1	9.40	Po-218	0.047 (2.291)	0.046 (2.715)	0.049 (2.413)	0.052 (2.521)
	9.40	Pb-214	0.047 (1.545)	0.048 (1.591)	0.051 (1.538)	-
	9.40	Bi-214	0.053 (1.454)	0.054 (1.537)	0.058 (1.363)	-
	9.40	Pb-212	0.058 (1.890)	0.060 (1.855)	0.063 (1.692)	-

TABLE 2

Activity Size Distributions
(calculated for unattached fractions (u.fn.) assumed as shown)

Trackless Mine:

Dated	Time	Species	Activity mean diameter (in μm) (GSD)			
			Previous	1% u.fn.	5% u.fn.	10% u.fn.
Feb 4	8.40	Po-218	0.084 (2.062)	0.086 (2.116)	0.089 (1.696)	0.103 (1.624)
	8.40	Pb-214	0.091 (1.479)	0.093 (1.59)	0.101 (1.562)	-
	8.40	Bi-214	0.096 (2.09)	0.096 (1.946)	0.098 (1.583)	0.109 (1.53)
Feb 5	8.40	Pb-214	0.053 (2.757)	0.054 (2.83)	0.059 (2.545)	0.065 (2.655)
	8.40	Bi-214	0.078 (2.498)	0.079 (2.566)	0.086 (2.49)	0.092 (2.102)
	8.40	Pb-212	0.092 (1.29)	0.094 (1.404)	-	-
Feb 6	9.00	Po-218	0.066 (2.398)	0.067 (2.345)	0.072 (2.029)	0.077 (1.726)
	9.00	Pb-214	0.073 (1.812)	0.074 (1.808)	0.077 (1.453)	0.085 (1.704)
	9.00	Bi-214	0.077 (1.75)	0.077 (1.633)	0.083 (1.622)	0.088 (1.473)
	9.00	Pb-212	0.09 (2.231)	0.096 (2.506)	0.10 (1.965)	0.105 (1.464)
	9.15	Po-218	0.069 (1.294)	0.071 (1.61)	0.076 (1.287)	-
	9.15	Bi-214	0.089 (1.557)	0.091 (1.511)	0.095 (1.489)	-
	9.15	Pb-212	0.103 (2.677)	0.107 (2.704)	0.124 (2.591)	0.132 (1.80)
Feb 7	9.10	RnWL	0.097 (1.839)	0.098 (1.711)	0.105 (1.586)	0.113 (1.417)
	9.40	RnWL	0.085 (1.86)	0.085 (1.827)	0.09 (1.619)	0.096 (1.286)
	10.10	RnWL	0.089 (2.55)	0.088 (2.41)	0.098 (2.326)	0.102 (1.64)
	10.40	RnWL	0.096 (1.806)	0.095 (1.593)	0.102 (1.524)	0.11 (1.499)
	8.40	Pb-212	0.125 (1.681)	0.130 (1.798)	-	-

TABLE 2 (cont'd)

Trackless Mine:

Dated	Time	Species	Activity mean diameter (in μm) (GSD)			
			Previous	1% u.fn.	5% u.fn.	10% u.fn.
Feb 7	13.15	Pb-212	0.107 (1.648)	0.103 (1.268)	0.109 (1.196)	-
	13.40	Pb-212	0.106 (1.622)	-	-	-
Feb 8	8.45	RnWL	0.079 (1.655)	0.08 (1.647)	0.083 (1.476)	0.092 (1.655)
	9.15	RnWL	0.089 (1.578)	0.089 (1.554)	0.097 (1.674)	-

TABLE 3

Unattached Fractions Raw Data
Alpha activities are shown as I( ) for four counting intervals.
Numbers in brackets indicate counts normalized with respect to the backup filter for pump flowrate and Trimet efficiency

a) Track Mine:

Jan. 30 Unattached Fraction Data:

Sample #	Pump Flowrate L/min	Trimet Eff.	Filter	I(1)	I(2)	I(3)	I(4)
1	5.1	0.43	Ref	2148 (2758)	8297 (10666)	11024 (14160)	4559 (5839)
	6.5	0.435	Back-up	2408	8957	11980	5091
2	5.1	0.448	Ref	2073 (2691)	8374 (10876)	10834 (14087)	4465 (5905)
	6.5	0.457	Backup	2169	8892	11521	4856
3	5.1	0.43	Ref	1693 (2184)	6569 (8473)	9767 (12594)	3358 (4315)
	6.5	0.435	Back-up	1787	7125	10695	4104

Jan. 31 Unattached Fraction Data:

Sample #	Pump Flowrate L/min	Trimet Eff.	Filter	I(1)	I(2)	I(3)	I(4)
1	5.1	0.436	Ref	2249 (2796)	8863 (11007)	11059 (14268)	4187 (5112)
	6.1	0.453	Back-up	2563	10169	13521	5026
2	4.9	0.445	Ref	2580 (3319)	10200 (13112)	13436 (17261)	5004 (6441)
	6.15	0.456	Backup	2853	12348	15618	5924
3	4.75	0.436	Ref	3257 (4419)	13156 (17856)	19396 (26331)	5691 (7709)
	6.2	0.453	Back-up	3920	16029	23500	6683

TABLE 3 (cont'd)

Feb. 1 Unattached Fraction Data:

Sample #	Pump Flowrate L/min	Trimet Eff.	Filter	I(1)	I(2)	I(3)	I(4)
1	5	0.444	Ref	8267	34108	39727	11108
				(10262)	(42327)	(49287)	(13778)
	6.1	0.452	Back-up	9422	38081	44754	12310
2	5.1	0.438	Ref	8818	36507	42547	11596
				(11100)	(45933)	(53513)	(14588)
	6.2	0.454	Backup	9100	40916	48203	13075
3	4.9	0.444	Ref	8110	33132	45312	9764
				(10279)	(41990)	(57423)	(12380)
	6.1	0.452	Back-up	8978	36988	49497	10630

(b) Trackless Mine:

Feb. 4 Unattached Fraction Data:

Sample #	Pump Flowrate L/min	Trimet Eff.	Filter	I(1)	I(2)	I(3)	I(4)
1	5.3	0.447	Ref	6408	25674	31525	8009
				(7250)	(29046)	(35677)	(9105)
	6	0.447	Back-up	6768	27434	33251	8690
2	5.2	0.444	Ref	6137	24926	30541	8432
				(7134)	(28969)	(35520)	(9951)
	6	0.448	Backup	6576	26863	33236	9264
	6	0.419	WS	44	164	276	138
				(47)	(175)	(295)	(147)
3	5.1	0.447	Ref†	6865	27225	38143	8519
				(7944)	(31497)	(44119)	(9851)
	5.9	0.447	Back-up	6597	26508	37532	8299

† Sampling time = 11 min; counting intervals: 1-4,8-24,29-59,359-459

TABLE 3 (cont'd)

Feb. 5 Unattached Fraction Data:

Sample #	Pump Flowrate L/min	Trimet Eff.	Filter	I(1)	I(2)	I(3)	I(4)
1	3.3	0.434	Ref	2880	11610	14187	3697
				(3333)	(13430)	(16407)	(4271)
	3.7	0.448	Back-up	3039	12115	15168	3944
2	3.4	0.458	Ref	3073	12058	15204	3980
				(3276)	(12842)	(16186)	(4255)
	3.7	0.449	Backup	3177	12377	15771	4303
	3.7	0.448	WS	11	58	73	60
3	3.1	0.434	Ref	2955	11492	16595	3557
				(3541)	(13773)	(19889)	(4256)
	3.6	0.448	Back-up	3233	12885	18215	4030

Feb. 6 Unattached Fraction Data:

Sample #	Pump Flowrate L/min	Trimet Eff.	Filter	I(1)	I(2)	I(3)	I(4)
1	5.1	0.431	Ref	5415	21429	26083	5633
				(6735)	(26628)	(32385)	(7008)
	6.2	0.441	Back-up	5667	23365	28090	6078
2	5.3	0.445	Ref	5506	22287	26539	5547
				(6172)	(24982)	(29761)	(6210)
	6	0.441	Backup	5813	23024	27675	6139
	6	0.415	WS	16	56	74	52
				(17)	(59)	(79)	(55)
3	5	0.431	Ref	5181	20516	28532	6311*
				(6353)	(25154)	(34994)	(7635)
	6	0.441	Back-up	5690	23805	33096	7192*

* Counted for extra 16 min.

TABLE 3 (cont'd)

UNATTACHED FRACTION DATA

Feb 7

Species	Sample #	Pump Flowrate L/min	Trimet Eff.	Meas. Mode	Counts
Rn ds	1	5.25	0.428	Ref	4719
		5.6	0.436	WS	4931
Rn ds	2	5.1	0.428	Ref	3833
		5.5	0.436	WS	3994
Rn ds	3	4.9	0.428	Ref	4008
		5.4	0.436	WS	3816
Rn ds	4	4.8	0.428	Ref	4168
		5.6	0.436	WS	4500
^{212}Pb	1	5.7	0.428	Ref	3194
		5.6	0.436	WS	3083
^{212}Pb	2	4.4	0.428	Ref	2238
		5.7	0.436	WS	2868
^{212}Pb	3*	4.1	0.44	Ref	2178
		6.0	0.457	WS	2912
^{212}Pb	4	3.6	0.428	Ref	1794
		5.7	0.436	WS	2811

* Sampling time = 15 min 11 sec

TABLE 3 (cont'd)

UNATTACHED FRACTION DATA Feb 8

Species	Sample #	Pump Flowrate L/min	Trimet Eff.	Meas. Mode	Counts
Rn ds	1	5.6	0.438	Ref	4332
		6.2	0.448	WS	4287
Rn ds	2	5.0	0.438	Ref	3563
		6.5	0.448	WS	4480
Rn ds	3	5.1	0.438	Ref	4505
		6.8	0.448	WS	5681
ThB	1	4.9	0.438	Ref	2571
		6.0	0.448	WS	3019
ThB	2	2.75	0.438	Ref	1372
		6.5	0.448	WS	2931
ThB	3	3.5	0.44	Ref	1723
		5.6	0.451	WS	2501
ThB	4	3.5	0.438	Ref	1720
		4.7	0.448	WS	2200

TABLE 4

Concentrations for Unattached Fractions Calculated from the Gross Alpha Counts in Table 3

(a) Track Mine:

Jan. 30 Concentrations for Unattached Fractions

Sample #	Filter mode	RaA pCi/L	RaB pCi/L	RaC pCi/L	ThB pCi/L
1	Ref	30.6	13.9	7.3	1.34
	Back-up	29	11.4	5.94	1.17
2	Ref.	24	13.4	7.8	1.29
	Back-up	18.6	11.05	6.4	1.06
3	Ref.	23.5	10.94	6	0.99
	Back-up	18.33	9.44	4.97	0.94

Jan. 31 Concentrations for Unattached Fractions

Sample #	Filter mode	RaA pCi/L	RaB pCi/L	RaC pCi/L	ThB pCi/L
1	Ref	29.2	14.6	8.2	1.2
	Back-up	28	14	7	1.18
2	Ref.	35.14	17.5	9.2	1.49
	Back-up	20.4	16.5	10.06	1.37
3	Ref.	42.9	23.9	13.06	1.78
	Back-up	36.2	21.5	12	1.54

TABLE 4 (cont'd)

Feb. 1 Concentrations for Unattached Fractions

Sample #	Filter mode	RaA pCi/L	RaB pCi/L	RaC pCi/L	ThB pCi/L
1	Ref Back-up	67.7 69.8	50.8 45.6	41.6 36.4	3.24 2.89
2	Ref. Back-up	71.1 39.6	54.3 52.1	44.1 38.8	3.36 3.01
3	Ref. Back-up	75 57	51.5 43.8	39.6 37.1	2.91 2.50

(b) Trackless Mine:

Feb. 4 Concentrations for Unattached Fractions:

Sample #	Filter mode	RaA pCi/L	RaB pCi/L	RaC pCi/L	ThB pCi/L
1	Ref Back-up	66.2 57.0	38.3 35.6	25.3 25	2.2 2.1
2	Ref. Back-up WS	61.5 57.3 0.92	38.1 35.9 0.32	25.6 23.2 0.01	2.4 2.2 0.04
3	Ref. Back-up	57.3 47.6	38.1 33	26.3 21.45	2.2 1.85

TABLE 4 (cont'd)

Feb. 5 Concentrations for Unattached Fractions:

Sample #	Filter mode	RaA pCi/L	RaB pCi/L	RaC pCi/L	ThB pCi/L
1	Ref	47.5	28.5	19.27	1.67
	Back-up	48.1	26.4	16.16	1.54
2	Ref.	54.9	27.9	16.71	1.66
	Back-up	55.5	27.1	15.6	1.68
	WS	-0.01	0.14	0.11	0.025
3	Ref.	62.7	30.82	18.28	1.71
	Back-up	49.9	28.2	18.62	1.62

Feb. 6 Concentrations for Unattached Fractions:

Sample #	Filter mode	RaA pCi/L	RaB pCi/L	RaC pCi/L	ThB pCi/L
1	Ref	61.6	34	23	1.66
	Back-up	43.8	30	21	1.44
2	Ref.	51	32.6	23.6	1.52
	Back-up	52.7	29.8	21.2	1.5
	WS	0.22	0.07	0.05	0.01
3	Ref.	57.5	32.4	23.3	1.87
	Back-up	42.5	31.9	22.4	1.73

TABLE 5

Unattached Fractions Calculations: Track Mine

Dated	Sample #	Pump Flowrate L/min	Linear Air Velocity cm/s	E†	EC_{ref}	$C_{ref}-C_{ws}$	f_u*	Species
Jan 30	1	6.5	27.17	0.52	15.95	1.6	0.10	Po-218
					7.228	2.5	0.35	Pb-214
					3.796	1.36	0.36	Bi-214
					0.708	0.17	0.24	Pb-212
	2	6.5	27.17	0.52	12.48	5.4	0.43	Po-218
					6.968	2.35	0.34	Pb-214
					4.056	1.4	0.34	Bi-214
					0.671	0.23	0.34	Pb-212
	3	6.5	27.17	0.52	12.22	5.17	0.42	Po-218
					5.689	1.5	0.26	Pb-214
					3.12	1.03	0.33	Bi-214
					0.515	0.05	0.10	Pb-212
Jan 31	1	6.1	25.5	0.54	15.768	1.2	0.08	Po-218
					7.884	0.6	0.08	Pb-214
					4.428	1.2	0.27	Bi-214
					0.648	0.02	0.03	Pb-212
	2	6.15	25.71	0.54	18.97	14.74	0.78	Po-218
					9.45	1.0	0.11	Pb-214
					4.97	-0.86	-0.17	Bi-214
					0.805	0.12	0.15	Pb-212
	3	6.2	25.92	0.53	22.737	6.7	0.29	Po-218
					12.667	2.4	0.19	Pb-214
					6.922	1.06	0.15	Bi-214
					0.943	0.24	0.25	Pb-212

cont'd...

TABLE 5 (cont'd)

Dated	Sample #	Pump Flowrate L/min	Linear Air Velocity cm/s	E†	EC_{ref}	$C_{ref}-C_{ws}$	f_u*	Species
	1	6.1	25.5	0.54	35.56	-2.1	-0.06	Po-218
					27.43	5.2	0.19	Pb-214
					22.46	5.2	0.23	Bi-214
					1.75	0.35	0.20	Pb-212
Feb 1	2	6.2	25.92	0.53	37.68	31.5	0.84	Po-218
					28.78	2.2	0.08	Pb-214
					23.37	5.3	0.23	Bi-214
					1.78	0.35	0.20	Pb-212
	3	6.1	25.5	0.54	40.5	18.0	0.44	Po-218
					27.81	7.7	0.28	Pb-214
					21.38	2.5	0.12	Bi-214
					1.57	0.41	0.26	Pb-212

† Screen collection efficiency
* Unattached fraction

TABLE 6

Unattached Fractions Calculations: Trackless Mine

Dated	Sample #	Pump Flowrate L/min	Linear Air Velocity cm/s	E†	EC_{ref}	$C_{ref}-C_{ws}$	f_u*	Species
	1	6	25.08	0.54	35.75	9.2	0.26	Po-218
					20.68	2.7	0.13	Pb-214
					13.66	0.3	0.02	Bi-214
					1.188	0.1	0.08	Pb-212
Feb 4	2	6	25.08	0.54	33.2	4.2	0.13	Po-218
					20.57	2.2	0.11	Pb-214
					13.82	2.4	0.17	Bi-214
					1.296	0.2	0.15	Pb-212
	3	5.9	24.66	0.55	31.51	9.7	0.31	Po-218
					20.95	5.1	0.24	Pb-214
					14.46	4.85	0.33	Bi-214
					1.21	0.35	0.29	Pb-212
	1	3.7	15.5	0.68	32.3	-0.6	-0.02	Po-218
					19.42	2.1	0.11	Pb-214
					13.10	3.11	0.24	Bi-214
					1.136	0.13	0.11	Pb-212
Feb 5	2	3.7	15.5	0.68	37.33	-0.6	-0.02	Po-218
					18.97	0.8	0.04	Pb-214
					11.36	1.11	0.10	Bi-214
					1.129	-0.02	-0.02	Pb-212
	3	3.6	15.05	0.69	43.263	13.2	0.30	Po-218
					21.266	2.62	0.12	Pb-214
					12.61	-0.34	-0.03	Bi-214
					1.18	0.09	0.08	Pb-212

cont'd.....

TABLE 6 (cont'd)

Dated	Sample #	Pump Flowrate L/min	Linear Air Velocity cm/s	E†	EC_{ref}	$C_{ref}-C_{ws}$	f_u*	Species
Feb 6	1	6.2	25.92	0.53	32.648	17.8	0.54	Po-218
					18.02	4.0	0.22	Pb-214
					12.19	2.0	0.16	Bi-214
					0.88	0.22	0.25	Pb-212
	2	6	25.08	0.54	27.54	-1.7	-0.06	Po-218
					17.6	2.8	0.16	Pb-214
					12.74	2.4	0.19	Bi-214
					0.821	0.02	0.02	Pb-212
	3	6	25.08	0.54	31.05	15.0	0.48	Po-218
					17.5	0.5	0.03	Pb-214
					12.58	0.9	0.07	Bi-214
					1.01	0.14	0.14	Pb-212
Feb 7	1	5.6	23.41	0.56	0.2	0.013	0.06	RnWL
	2	5.5	23	0.57	0.17	0.016	0.09	RnWL
	3	5.4	22.57	0.57	0.185	0.049	0.26	RnWL
	4	5.6	23.41	0.56	0.193	0.031	0.16	RnWL
	1	5.6	23.41	0.56	1.07	0.07	0.06	Pb-212
	2	5.7	23.83	0.56	0.97	0.05	0.05	Pb-212
	3	6	25.08	0.54	0.94	0.21	0.22	Pb-212
	4	5.7	23.83	0.56	0.952	0.05	0.05	Pb-212
Feb 8	1	6.2	25.92	0.53	0.159	0.038	0.24	RnWL
	2	6.5	27.17	0.52	0.144	0.015	0.10	RnWL
	3	6.8	28.4	0.51	0.175	0.026	0.15	RnWL
	1	6	25.08	0.54	0.945	0.11	0.12	Pb-212
	2	6.5	27.17	0.52	0.863	0.19	0.22	Pb-212
	3	5.6	23.41	0.56	0.913	0.19	0.21	Pb-212
	4	4.7	19.65	0.61	1.0	0.12	0.12	Pb-212

† Screen collection efficiency
* Unattached fraction

TABLE 7

Statistical Means, Best Estimates of Standard Deviations and Uncertainties in Concentration Measurements for the Unattached Fraction

Mine	Mean unattached fractions $\pm\sigma_{n-1}$ (uncertainties in concentration measurements are given in brackets)				
	^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	RnWL
Track	0.37 ± 0.30	0.21 ± 0.10	0.21 ± 0.16	0.20 ± 0.09	--
	(±0.29 - 0.32)	(±0.07)	(±0.17 - 0.20)	(±0.05)	(±0.07)
Trackless	0.21 ± 0.22	0.13 ± 0.07	0.14 ± 0.12	0.13 ± 0.09	0.15 ± 0.08

TABLE 8a

Unatached Fractions from Gross Alpha Counts

Track Mine:

Dated	Sample #	f_{2-5}	f_{9-25}	f_{30-60}	f_{40-70}	$f_{450-460}$
Jan 30	1	0.24	0.31	—	0.30	0.25
	2	0.37	0.35	—	0.35	0.34
	3	0.35	0.31	0.29	—	0.09
Jan 31	1	0.15	0.14	—	0.10	0.03
	2	0.26	0.11	—	0.18	0.15
	3	0.21	0.19	0.20	—	0.25
Feb 1	1	0.15	0.19	—	0.17	0.20
	2	0.34	0.21	—	0.19	0.20
	3	0.23	0.22	0.26	—	0.26
Mean $\pm\sigma_{n-1}$		0.25±0.08	0.22±0.08	0.25±0.05	0.21±0.09	0.20 ±0.09

TABLE 8b

Unattached Fractions from Gross Alpha Counts

Trackless Mine:

Dated	Sample #	f_{2-5}	f_{9-25}	f_{30-60}	f_{40-70}	$f_{450-460}$
Feb 4	1	0.12	0.10	—	0.13	0.08
	2	0.14	0.13	—	0.12	0.13
	3	0.31	0.29	0.27	—	0.29
Feb 5	1	0.13	0.14	—	0.11	0.11
	2	0.04	0.05	—	0.04	-0.02
	3	0.13	0.09	0.12	—	0.08
Feb 6	1	0.30	0.23	—	0.25	0.25
	2	0.11	0.14	—	0.13	0.02
	3	0.19	0.10	0.10	—	0.11
Mean $\pm\sigma_{n-1}$		0.16±0.09	0.14±0.07	0.16±0.09	0.13±0.07	0.12±0.10

TABLE 8c

Probability p that Back-up Filter Counts, n_{buf}, are Greater than Reference Filter Counts, n_{ref}

n_{ref}	u.fn. (%)	n_{buf}	$x-\mu$	$\sigma = \sqrt{\sigma_1^2+\sigma_2^2}$	$z = (x-\mu)/\sigma$	F(z)	p=1-F(z)
500	1	495	5	31.54	0.158	0.5636	0.4364
500	2	490	10	31.5	0.317	0.6255	0.3745
500	5	475	25	31.22	0.80	0.788	0.2120
500	10	450	50	30.82	1.62	0.9474	0.0526
500	20	400	100	30	3.33	0.9996	0.0004
1000	1	990	10	44.6	0.224	0.5871	0.4129
1000	2	980	20	44.5	0.449	0.6736	0.3264
1000	5	950	50	44.16	1.13	0.8708	0.1290
1000	10	900	100	43.6	2.29	0.9890	0.011
1000	20	800	200	42.43	4.7	1	0
2000	1	1980	20	63.09	0.317	0.6255	0.3745
2000	2	1960	40	62.93	0.636	0.7389	0.2611
2000	5	1900	100	62.45	1.60	0.9452	0.0548
2000	10	1800	200	61.64	3.24	0.9994	0.0006
4000	1	3960	40	89.22	0.45	0.6736	0.3264
4000	2	3920	80	89	0.90	0.8159	0.1841
4000	5	3800	200	88.32	2.26	0.9881	0.0119
4000	10	3600	400	87.18	4.59	1	0
6000	1	5940	60	109.27	0.55	0.7088	0.2912
6000	2	5880	120	108.99	1.1	0.8643	0.1357
6000	5	5700	300	108.17	2.77	0.9972	0.0028
6000	10	5400	600	106.77	5.62	1	0

TABLE 8d

Results of Paired t-test on the Difference between ref. and buf. Concentrations. The table indicates acceptance or rejection of null-hypothesis $\mu_1 - \mu_2 = 0$

Mine	Level of significance	Po-218	Pb-214	Bi-214	Pb-212
Track	0.01	Accepted	Rejected	Rejected	Rejected
	0.05	Rejected	Rejected	Rejected	Rejected
Trackless	0.01	Rejected	Rejected	Rejected	Rejected

TABLE 9

Unattached Fractions Based on Wire Screen Counting for Mixtures of Po-218, Pb-214, Bi-214 and Pb-212 in Four Counting Intervals. The geometric counting efficiency of the screen is taken as 0.5. (The screen collection efficiencies are listed in Table 6.)

Date	f_{2-5}	f_{9-25}	f_{40-70}	$f_{450-460}$
Feb 4	0.02	0.02	0.03	0.05
Feb 5	0.01	0.01	0.01	0.04
Feb 6	0.01	0.01	0.01	0.03

TABLE 9a

Overall Relative Standard Deviation (Gross Alpha Counts)

Date	ΔV/V	Method	Fractional RSD for counting intervals			
			2-5	9-25	40-70	360-460
Feb 4	0.05	Ref-Buf	0.073	0.071	0.071	0.072
		WS	0.162	0.104	0.092	0.110
	0.10	Ref-Buf	0.142	0.142	0.142	0.142
		WS	0.203	0.160	0.153	0.164
Feb 5	0.05	Ref-Buf	0.075	0.072	0.072	0.074
		WS	0.310	0.150	0.137	0.148
	0.10	Ref-Buf	0.144	0.142	0.142	0.143
		WS	0.333	0.193	0.184	0.192
Feb 6	0.05	Ref-Buf	0.073	0.071	0.071	0.073
		WS	0.253	0.148	0.133	0.153
	0.10	Ref-Buf	0.143	0.142	0.142	0.143
		WS	0.281	0.192	0.181	0.196

TABLE 9b

Overall Relative Standard Deviation (Concentrations)

Date	ΔV/V	Method	Fractional RSD for radionuclides			
			^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb
Feb 4	0.05	Ref-Buf	0.408	0.091	0.242	0.072
		WS	0.492	0.164	6.93	0.108
	0.10	Ref-Buf	0.798	0.179	0.478	0.142
		WS	0.727	0.227	8.79	0.163
Feb 5	0.05	Ref-Buf	0.332	0.094	0.273	0.074
		WS	293.35*	0.264	0.556	0.145
	0.10	Ref-Buf	0.633	0.183	0.533	0.143
		WS	313.63*	0.305	0.686	0.190
Feb 6	0.05	Ref-Buf	0.413	0.093	0.229	0.073
		WS	0.987	0.362	0.736	0.177
	0.10	Ref-Buf	0.806	0.183	0.452	0.143
		WS	1.15	0.398	0.839	0.215

* The concentration of Po-218 on the wire screen was calculated to be -0.01 pCi/L. For the statistical calculation, this was replaced by a nominal positive concentration of 0.001 pCi/L.

TABLE 9c

Efficiency Calibration Data for Trimet Alpha Counters. Counts registered ovr a 5 minute interval are listed. Trimet efficiencies based on a 1740 dPm Am-241 source are given in brackets.

Dated	Trimet nos.				
	#1	#2	#3	#4	#5
Jan 29	3864 (0.444)	3981 (0.458)	3922 (0.451)	3939 (0.453)	3958 (0.455)
Jan 30	3743 (0.43)	3895 (0.448)	3786 (0.435)	3974 (0.457)	4158 (0.478)
Jan 31	3795 (0.436)	3873 (0.445)	3939 (0.453)	3964 (0.456)	4078 (0.469)
Feb 1	3862 (0.444)	3809 (0.438)	3935 (0.452)	3881 (0.446)	3951 (0.454)
Feb 4	3889 (0.447)	3863 (0.444)	3890 (0.447)	3900 (0.448)	4069 (0.468)
Feb 5	3776 (0.434)	3984 (0.458)	3901 (0.448)	3910 (0.449)	3566 (0.41)
Feb 6	3751 (0.431)	3868 (0.445)	3840. (0.441)	3834 (0.441)	3610 (0.415)
Feb 7	3722 (0.428)	3827 (0.44)	3793 (0.436)	3978 (0.457)	3857 (0.443)
Feb 8	3807 (0.438)	3829 (0.44)	3896 (0.448)	3921 (0.451)	4048 (0.465)

Approximate average number of counts, N = 3800

Relative error = $\frac{\sqrt{N}}{N} = \frac{1}{\sqrt{3800}} = 0.0162$

Therefore relative standard deviation for counting can be taken, approximately as equal to 0.02.

TABLE 9d

Overall Standard Deviations (Gross Alpha Counts) Including Assigned Uncertainties for Counters and Wire Screen Collection and Counting Efficiencies $\Delta V/V = 0.05$

Date	Method	Fractional RSD for counting intervals			
		2-5	9-25	40-70	360-460
Feb 4	Ref-Buf	0.084	0.082	0.082	0.083
	WS	0.195	0.150	0.142	0.154
Feb 5	Ref-Buf	0.086	0.083	0.083	0.085
	WS	0.328	0.185	0.174	0.196
Feb 6	Ref-Buf	0.084	0.082	0.082	0.084
	WS	0.275	0.183	0.171	0.187

TABLE 9e

Activity Balance for Reference Filter versus Sum of Back-up Filter and Wire Screen Counts: Uncertainties are calculated as $\sqrt{N}$; percent difference calculated as actual difference/reference counts.

Date	Interval #	N_{WS}*	N_{Buf}	N_{Buf+WS}	N_{Ref}	Difference ($N_{Ref}-N_{Buf+WS}$)	% Difference
Feb 1	1	174 ±13	6576 ±81	6750 ±82	7134 ±84	218 to 550	3 to 8
	2	648 ±25	26863 ±164	27511 ±166	28969 ±170	1122 to 1794	4 to 6
	3	1093 ±33	33236 ±182	34329 ±185	35520 ±188	818 to 1564	2 to 4
	4	544 ±23	9264 ±96	9808 ±99	9951 ±100	-56 to 342	-0.6 to 3
Feb 5	1	32 ±6	3177 ±56	3209 ±57	3276 ±57	-47 to 181	-1.4 to 5
	2	171 ±13	12377 ±111	12548 ±112	12842 ±113	69 to 295	0.5 to 2
	3	215 ±15	15771 ±126	15986 ±126	16186 ±127	-53 to 453	-0.3 to 3
	4	176 ±13	4303 ±66	4479 ±67	4255 ±65	-356 to -92	-8 to (-2)
Feb 6	1	63 ±8	5813 ±76	5876 ±77	6172 ±79	140 to 452	2 to 7
	2	218 ±15	23024 ±152	23242 ±152	24982 ±158	1430 to 2050	6 to 8
	3	293 ±17	27675 ±166	27968 ±167	29761 ±172	1454 to 2132	5 to 7
	4	204 ±14	6139 ±78	6343 ±80	6210 ±79	-292 to 26	-5 to 0.4

* The wire screen counts are corrected for collection efficiency based on Table 5 and a wire screen counting efficiency of 0.5 (Ge72). The considerable and unknown uncertainties in both these corrections are not reflected in Table 9e in N_{WS}, which is based on counting statistics alone.

TABLE 10

Aerosol Size Distribution Data
(Flowrate = 60 mL/sec)

Track Mine:

Date	Time	Aerosol concn. (#/cm^3)	Count median diameter (μm)	GSD
Jan 30	9.40	64,000	0.051	2.341
	11.40	60,000	0.053	1.52
	12.50	50,000	0.050	2.682
	13.50	37,000	0.051	2.145
Jan 31	9.35	50,000	0.062	2.422
	10.00	37,000	0.065	1.398
	11.50	42,000	0.058	2.188
	13.00	43,000	0.061	1.723
	14.05	30,000	0.072	2.560
Feb 1	10.25	73,000	0.046	1.596
	12.20	75,000	0.050	1.759
	13.25	75,000	0.048	1.564

Trackless Mine:

Date	Time	Aerosol concn. (#/cm^3)	Count median diameter (μm)	GSD
Feb 4	9.30	128,000	0.088	1.837
	12.40	114,000	0.094	1.435
Feb 5	9.20	107,000	0.070	1.150
	11.50	144,000	0.084	1.485
	12.50	160,000	0.032	2.505
Feb 6	9.45	126,000	0.062	1.547
	12.00	135,000	0.047	1.976
	13.05	132,000	0.076	1.409
Feb 8	10.05	108,000	0.070	1.503
	10.20	108,000	0.070	1.427

TABLE 11a

Results of Theoretical Unattached Fraction Determination

Track Mine:

Date	Time	Aerosol concn (#/cm^3)	Particle Diameter (μm)	λ_s (min^{-1})	Effective time, T (min)	f_{Po-218}	f_{Pb-214}	f_{Bi-214}
Jan 30	9.40	64,000	0.051	1.035	5	0.26	0.25	0.11
					10	0.21	0.13	0.03
					20	0.18	0.06	0.008
					40	0.18	0.03	0.002
					60	0.18	0.03	0.001
	11.40	60,000	0.53	1.045	5	0.26	0.25	0.11
					10	0.20	0.12	0.03
					20	0.18	0.06	0.008
					40	0.18	0.03	0.002
					60	0.18	0.03	0.001
	12.50	50,000	0.05	0.778	5	0.33	0.32	0.17
					10	0.25	0.16	0.05
					20	0.23	0.08	0.01
					40	0.23	0.04	0.004
					60	0.23	0.04	0.002
	13.50	37,000	0.051	0.598	5	0.40	0.39	0.24
					10	0.31	0.21	0.08
					20	0.28	0.11	0.02
					40	0.27	0.06	0.007
					60	0.27	0.05	0.004

cont'd.....

TABLE 11a (cont'd)

Date	Time	Aerosol concn (#/cm^3)	Particle Diameter (μm)	λ_s (min^{-1})	Effective time, T (min)	f_{Po-218}	f_{Pb-214}	f_{Bi-214}
Jan 31	9.35	50,000	0.062	1.175	5	0.24	0.22	0.09
					10	0.18	0.11	0.02
					20	0.16	0.05	0.006
					40	0.16	0.03	0.002
					60	0.16	0.02	0.001
	10.00	37,000	0.065	0.951	5	0.28	0.27	0.13
					10	0.21	0.14	0.04
					20	0.19	0.07	0.009
					40	0.19	0.04	0.003
					60	0.19	0.03	0.002
	11.50	42,000	0.058	0.869	5	0.30	0.29	0.14
					10	0.23	0.15	0.04
					20	0.21	0.07	0.01
					40	0.21	0.04	0.003
					60	0.21	0.03	0.002
	13.00	43,000	0.061	0.979	5	0.28	0.26	0.12
					10	0.21	0.13	0.03
					20	0.19	0.06	0.008
					40	0.19	0.04	0.003
					60	0.19	0.03	0.001
	14.05	30,000	0.072	0.935	5	0.29	0.27	0.13
					10	0.22	0.14	0.04
					20	0.20	0.07	0.009
					40	0.20	0.04	0.003
					60	0.19	0.03	0.002

cont'd.....

TABLE 11a (cont'd)

Date	Time	Aerosol concn #/cm^3	Particle Diameter (μm)	λ_s (min^{-1})	Effective time, T (min)	f_{Po-218}	f_{Pb-214}	f_{Bi-214}
Feb 1	10.25	73,000	0.046	0.967	5	0.28	0.26	0.12
					10	0.21	0.13	0.03
					20	0.19	0.06	0.009
					40	0.19	0.04	0.003
					60	0.19	0.03	0.001
	12.20	75,000	0.05	1.167	5	0.24	0.22	0.09
					10	0.18	0.11	0.02
					20	0.16	0.05	0.006
					40	0.16	0.03	0.002
					60	0.16	0.02	0.001
	13.25	75,000	0.048	1.079	5	0.25	0.24	0.10
					10	0.19	0.12	0.03
					20	0.17	0.06	0.007
					40	0.17	0.03	0.002
					60	0.17	0.02	0.001

TABLE 11b

Results of Theoretical Unattached Fraction Determination

Trackless Mine:

Date	Time	Aerosol concn (#/cm^3)	Particle Diameter (μm)	λ_s (min^{-1})	Effective time, T (min)	f_{Po-218}	f_{Pb-214}	f_{Bi-214}
Feb 4	9.30	128,000	0.088	5.789	5	0.05	0.05	0.005
					10	0.04	0.02	0.001
					20	0.04	0.01	0.0002
					40	0.04	0.006	7×10^{-5}
					60	0.04	0.005	4×10^{-5}
	12.40	114,000	0.094	5.817	5	0.05	0.05	0.005
					10	0.04	0.02	0.001
					20	0.04	0.01	0.0002
					40	0.04	0.006	7×10^{-5}
					60	0.04	0.005	4×10^{-5}
Feb 5	9.20	107,000	0.07	3.162	5	0.10	0.09	0.01
					10	0.07	0.04	0.003
					20	0.07	0.02	0.0008
					40	0.07	0.01	0.0002
					60	0.07	0.009	0.0001
	11.50	144,000	0.084	5.978	5	0.05	0.05	0.004
					10	0.04	0.02	0.001
					20	0.04	0.01	0.0002
					40	0.04	0.006	7×10^{-5}
					60	0.04	0.005	4×10^{-5}

cont'd..

TABLE 11b (cont'd)

Date	Time	Aerosol concn (#/cm^3)	Particle Diameter (μm)	λ_a (min^{-1})	Effective time, T (min)	f_{Po-218}	f_{Pb-214}	f_{Bi-214}
	12.50	160,000	0.032	1.044	5	0.26	0.25	0.11
					10	0.20	0.12	0.03
					20	0.18	0.06	0.008
					40	0.18	0.03	0.002
					60	0.18	0.03	0.001
Feb 6	9.45	126,000	0.062	2.960	5	0.10	0.09	0.02
					10	0.08	0.04	0.004
					20	0.07	0.02	0.001
					40	0.07	0.01	0.0003
					60	0.07	0.009	0.0002
	12.00	135,000	0.047	1.865	5	0.16	0.15	0.04
					10	0.12	0.07	0.01
					20	0.11	0.03	0.002
					40	0.11	0.02	0.0007
					60	0.11	0.01	0.0004
	13.05	132,000	0.076	4.550	5	0.07	0.06	0.007
					10	0.05	0.03	0.002
					20	0.05	0.01	0.0004
					40	0.05	0.008	0.0001
					60	0.05	0.006	7×10^{-5}
Feb 8	10.05 10.20	108.000	0.07	3.192	5	0.10	0.09	0.01
					10	0.07	0.04	0.003
					20	0.07	0.02	0.0008
					40	0.07	0.01	0.0002
					60	0.07	0.008	0.0001

TABLE 11c

Weighted Sum of Theoretical Unattached Fractions for 20 Minute Old Air. Basis is 21 strips in the size distribution.

Date	Time	Aerosol concn. (#/cm^3)	Particle dia (μm) (GSD)	Unattached fractions		
				f_{Po-218}	f_{Po-214}	f_{Bi-214}
Jan 30	9.40	64,000	0.051 (2.341)	0.23	0.16	0.11
	11.40	60,000	0.053 (1.52)	0.24	0.12	0.04
	12.50	50,000	0.05 (2.682)	0.23	0.18	0.15
	13.50	37,000	0.051 (2.145)	0.27	0.20	0.16
Jan 31	9.35	50,000	0.062 (2.422)	0.22	0.14	0.10
	10.00	37,000	0.065 (1.398)	0.29	0.13	0.04
	11.50	42,000	0.058 (2.188)	0.24	0.17	0.12
	13.00	43,000	0.061 (1.723)	0.26	0.14	0.07
	14.05	30,000	0.072 (2.56)	0.23	0.17	0.13
Feb 1	10.25	73,000	0.046 (1.596)	0.25	0.13	0.06
	12.20	75,000	0.05 (1.759)	0.23	0.12	0.06
	13.25	75,000	0.048 (1.564)	0.23	0.11	0.04
Feb 4	9.30	128,000	0.088 (1.837)	0.08	0.03	0.003
	12.40	114,000	0.094 (1.435)	0.07	0.02	0.001
Feb 5	9.20	107,000	0.07 (1.15)	0.17	0.05	0.003
	11.50	144,000	0.084 (1.485)	0.07	0.02	0.001

cont'd.....

TABLE 11c (cont'd)

Date	Time	Aerosol concn. (#/cm^3)	Particle dia (μm) (GSD)	Unattached fractions		
				f_{Po-218}	f_{Po-214}	f_{Bi-214}
Feb 5	12.50	160,000	0.032 (2.505)	0.22	0.16	0.12
Feb 6	9.45	126,000	0.062 (1.547)	0.13	0.04	0.007
	13.05	132,000	0.076 (1.409)	0.09	0.03	0.002
Feb 8	10.05	108,000	0.07 (1.503)	0.12	0.04	0.005
	10.20	108,000	0.07 (1.427)	0.12	0.04	0.004

Table 12

Results of Theoretical Calculations of Unattached Fractions for Different Diffusion Coefficients. Effective Time T = 20 min. The hybrid theory of attachment was used.

Date	Time	Aerosol concn ($\#/cm^3$)	Particle dia. (μm)	D (cm^2/s)	λ_s (min^{-1})	f_{Po-218}	f_{Po-214}	f_{Bi-214}
Jan 30	9.40	64,000	0.051	0.054	1.035	0.18	0.06	0.008
				0.02	0.963	0.19	0.07	0.009
	11.40	60,000	0.053	0.054	1.045	0.18	0.06	0.008
				0.02	0.968	0.19	0.07	0.009
	12.50	50,000	0.05	0.054	0.778	0.23	0.08	0.01
				0.02	0.726	0.24	0.09	0.02
	13.50	37,000	0.051	0.054	0.598	0.28	0.11	0.02
				0.02	0.557	0.29	0.11	0.03
Jan 31	9.35	50,000	0.062	0.054	1.175	0.16	0.05	0.006
				0.02	1.066	0.18	0.06	0.007
	10.00	37,000	0.065	0.054	0.951	0.19	0.07	0.009
				0.02	0.856	0.21	0.07	0.01
	11.50	42,000	0.058	0.054	0.869	0.21	0.07	0.01
				0.02	0.796	0.22	0.08	0.01

cont'd.....

TABLE 12 (cont'd)

Date	Time	Aerosol concn (#/cm^3)	Particle dia. (μm)	D (cm^2/s)	λ_s (min^{-1})	f_{Po-218}	f_{Po-214}	f_{Bi-214}
	13.00	43,000	0.061	0.054 0.02	0.979 0.891	0.19 0.20	0.06 0.07	0.008 0.01
	14.05	30,000	0.072	0.054 0.02	0.935 0.828	0.20 0.22	0.07 0.08	0.009 0.01
Feb 1	10.25	73,000	0.046	0.054 0.02	0.967 0.910	0.19 0.20	0.06 0.07	0.009 0.01
	12.20	75,000	0.05	0.054 0.02	1.167 1.089	0.16 0.17	0.05 0.06	0.006 0.007
	13.25	75,000	0.048	0.054 0.02	1.079 1.011	0.17 0.18	0.06 0.06	0.007 0.008
Feb 4	9.30	128,000	0.088	0,054 0.02	5.789 4.934	0.04 0.04	0.01 0.01	0.0002 0.0003
	12.40	114,000	0.094	0.054 0.02	5.817 4.888	0.04 0.04	0.01 0.01	0.0002 0.0003

cont'd.....

TABLE 12 (cont'd)

Date	Time	Aerosol concn (#/cm^3)	Particle dia. (μm)	D (cm^2/s)	λ_s (min^{-1})	f_{Po-218}	f_{Po-214}	f_{Bi-214}
Feb 5	9.20	107,000	0.07	0.054 0.02	3.162 2.815	0.07 0.07	0.02 0.02	0.0008 0.0001
	11.50	144,000	0.084	0.054 0.02	5.978 5.144	0.04 0.04	0.01 0.01	0.002 0.003
	12.50	160,000	0.032	0.054 0.02	1.044 1.010	0.18 0.18	0.06 0.06	0.008 0.008
Feb 6	9.45	126,000	0.062	0.054 0.02	2.960 2.686	0.07 0.08	0.02 0.02	0.001 0.001
	12.00	135,000	0.047	0.054 0.02	1.865 1.751	0.11 0.12	0.03 0.04	0.002 0.003
	13.05	132,000	0.076	0.054 0.02	4.550 3.993	0.05 0.05	0.01 0.02	0.0004 0.0005
Feb 8	10.05) 10.20)	108,000	0.07	0.054 0.02	3.192 2.841	0.07 0.07	0.02 0.02	0.0008 0.001

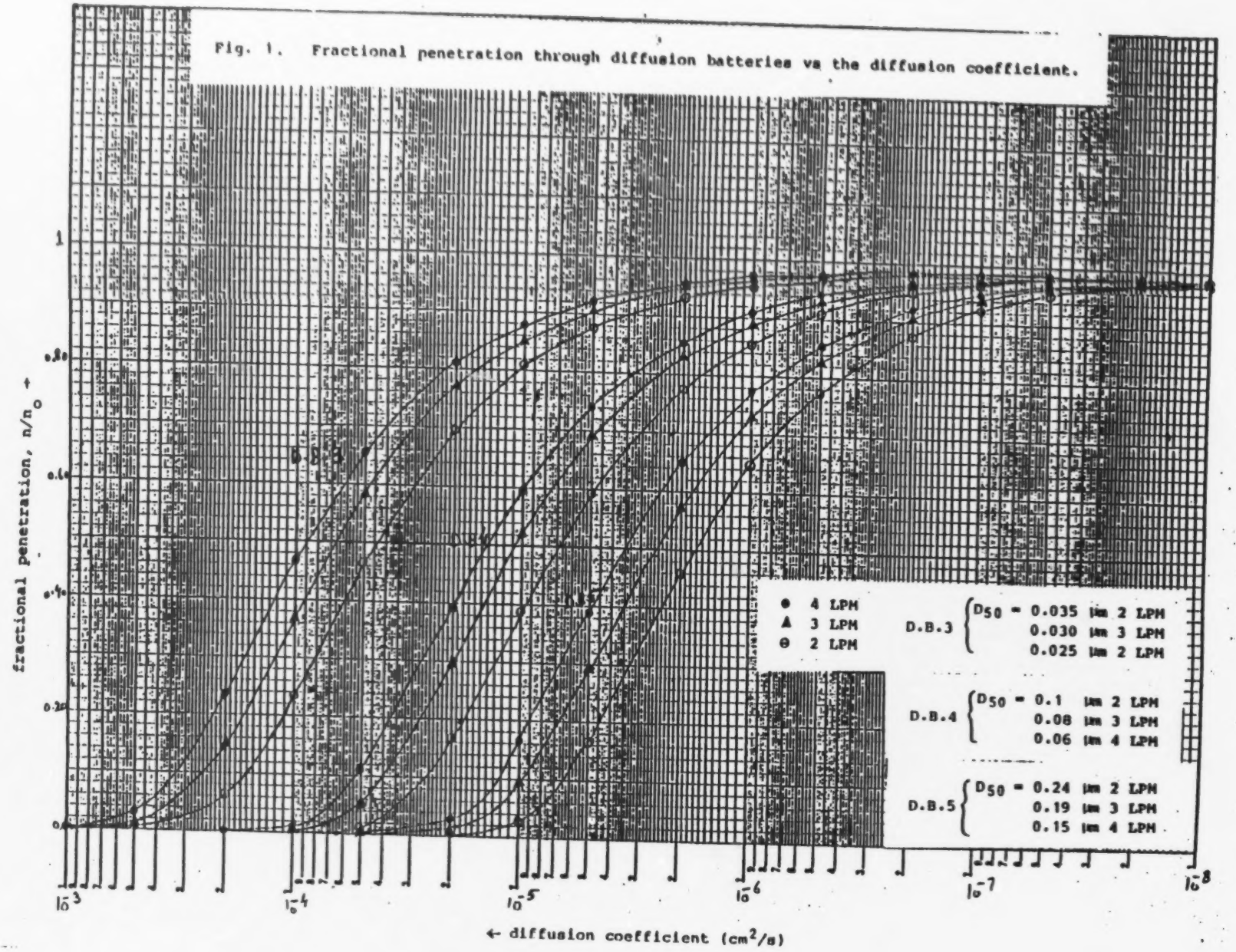


Fig. 1. Fractional penetration through diffusion batteries vs the diffusion coefficient.

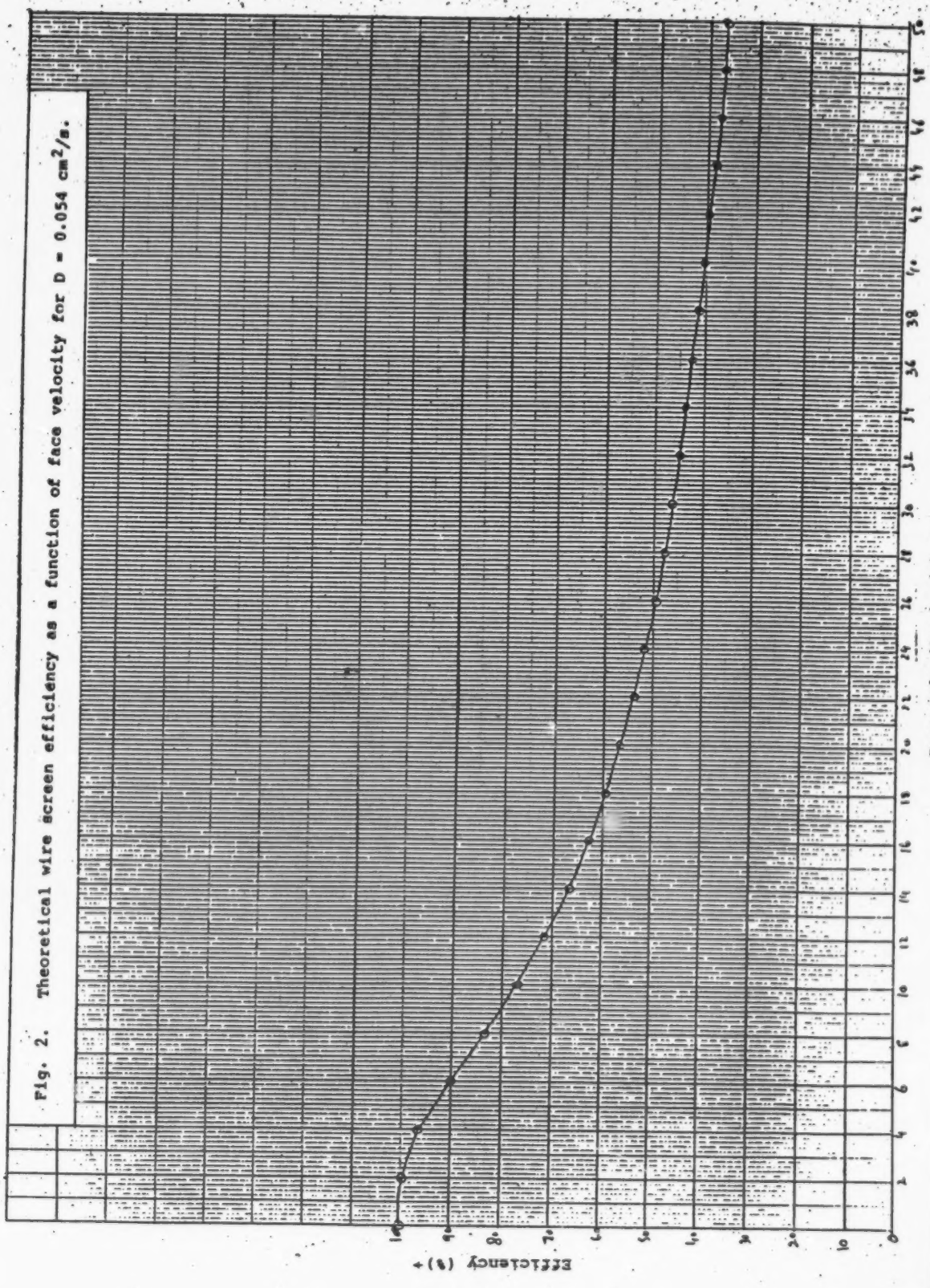


Fig. 2. Theoretical wire screen efficiency as a function of face velocity for D = 0.054 cm^2/s.

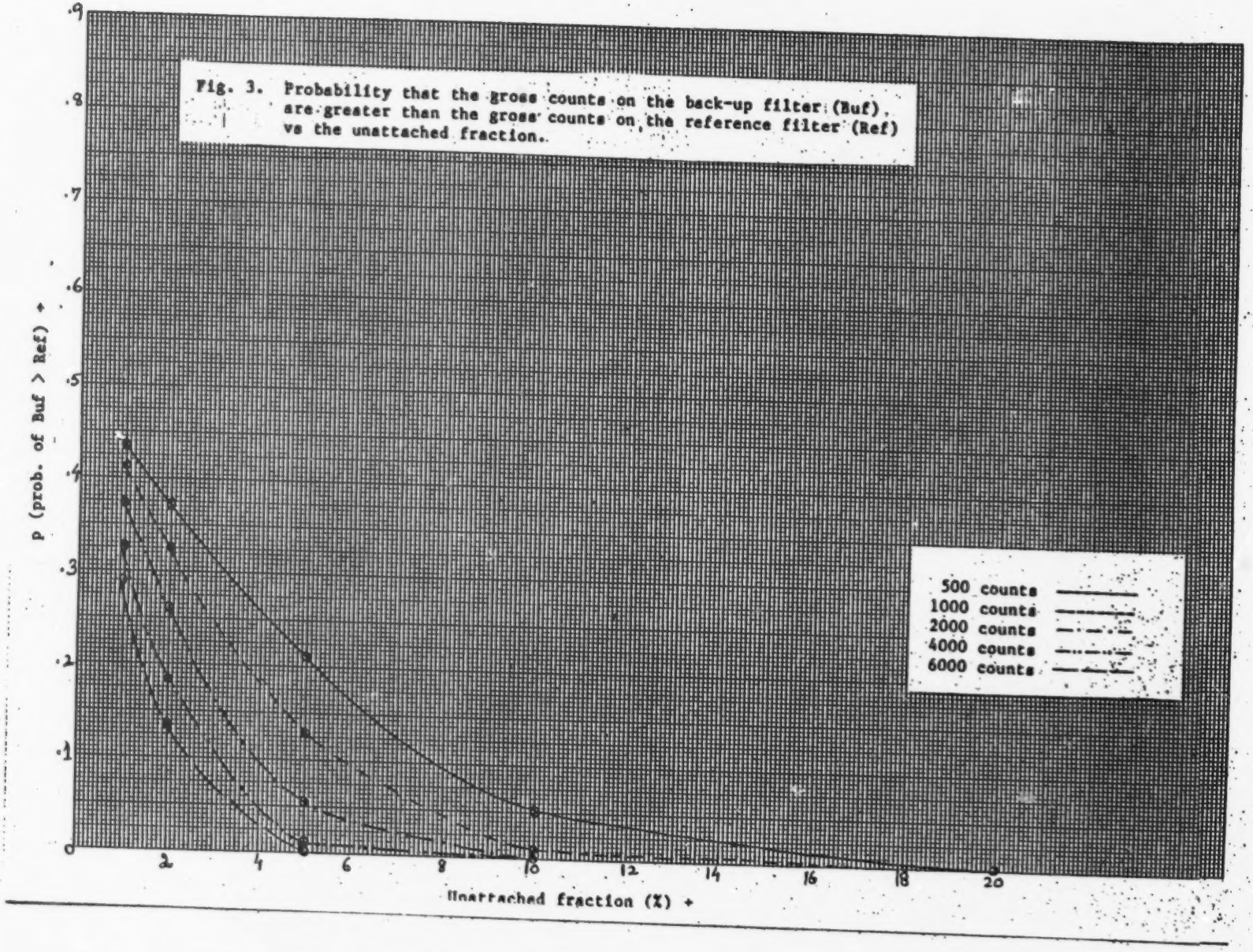


Fig. 3. Probability that the gross counts on the back-up filter (Buf), are greater than the gross counts on the reference filter (Ref) vs the unattached fraction.
P (prob. of Buf > Ref) →
Unattached fraction (%) →
500 counts
1000 counts
2000 counts
4000 counts
6000 counts
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
2
4
6
8
10
12
14
16
18
20

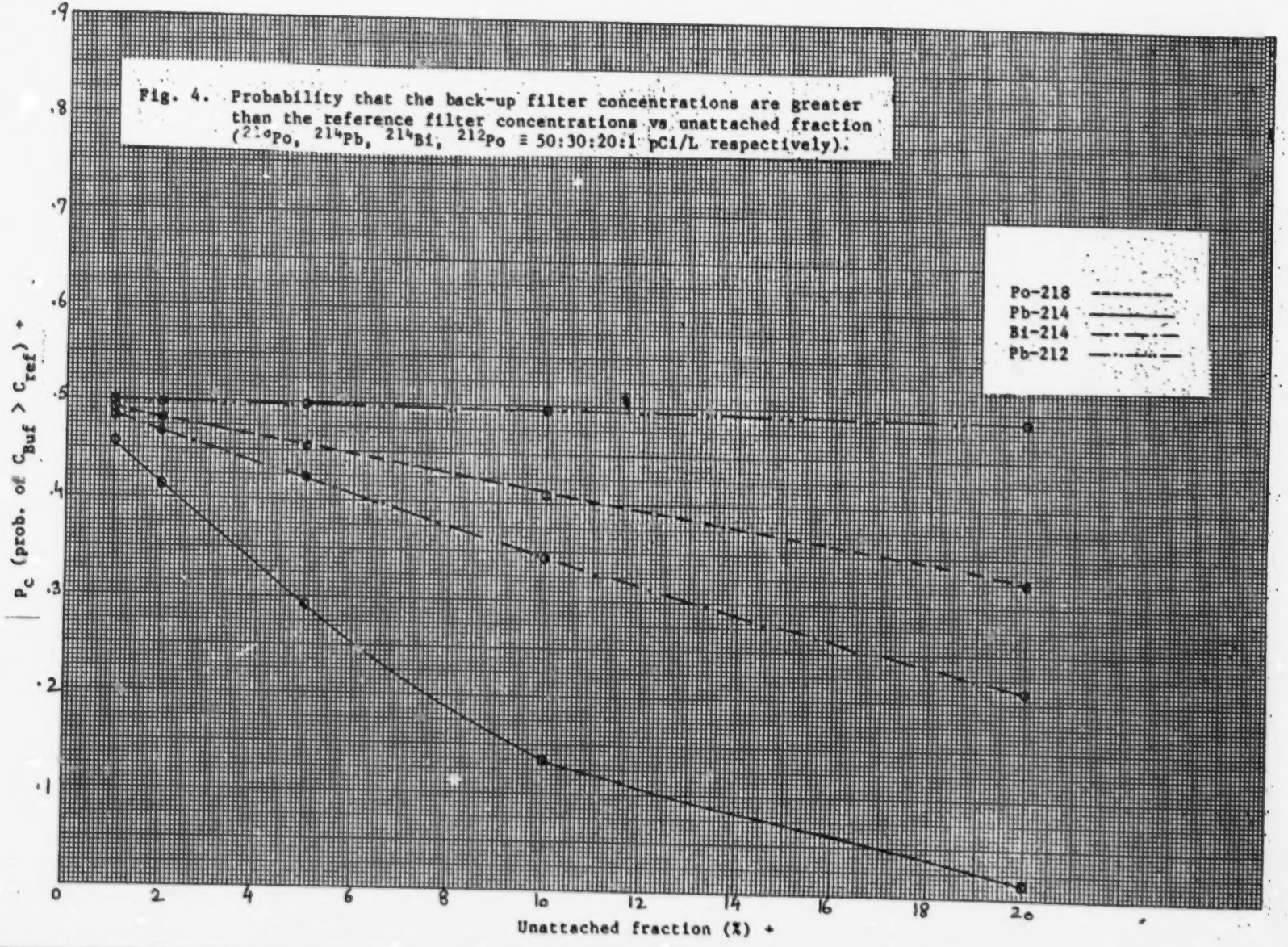


Fig. 4. Probability that the back-up filter concentrations are greater than the reference filter concentrations vs unattached fraction (^{218}Po, ^{214}Pb, ^{214}Bi, ^{212}Po ≡ 50:30:20:1 pCi/L respectively).

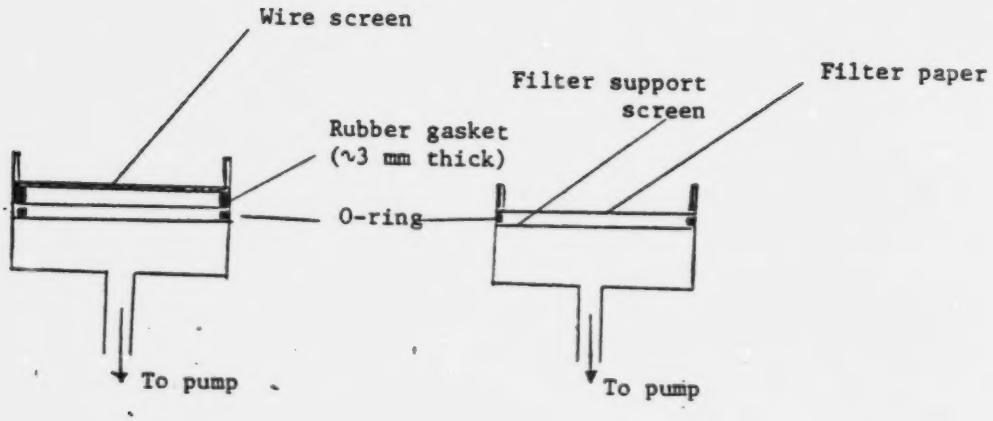


Fig. 4a. A schematic diagram of the sampling arrangement for determining unattached fractions.

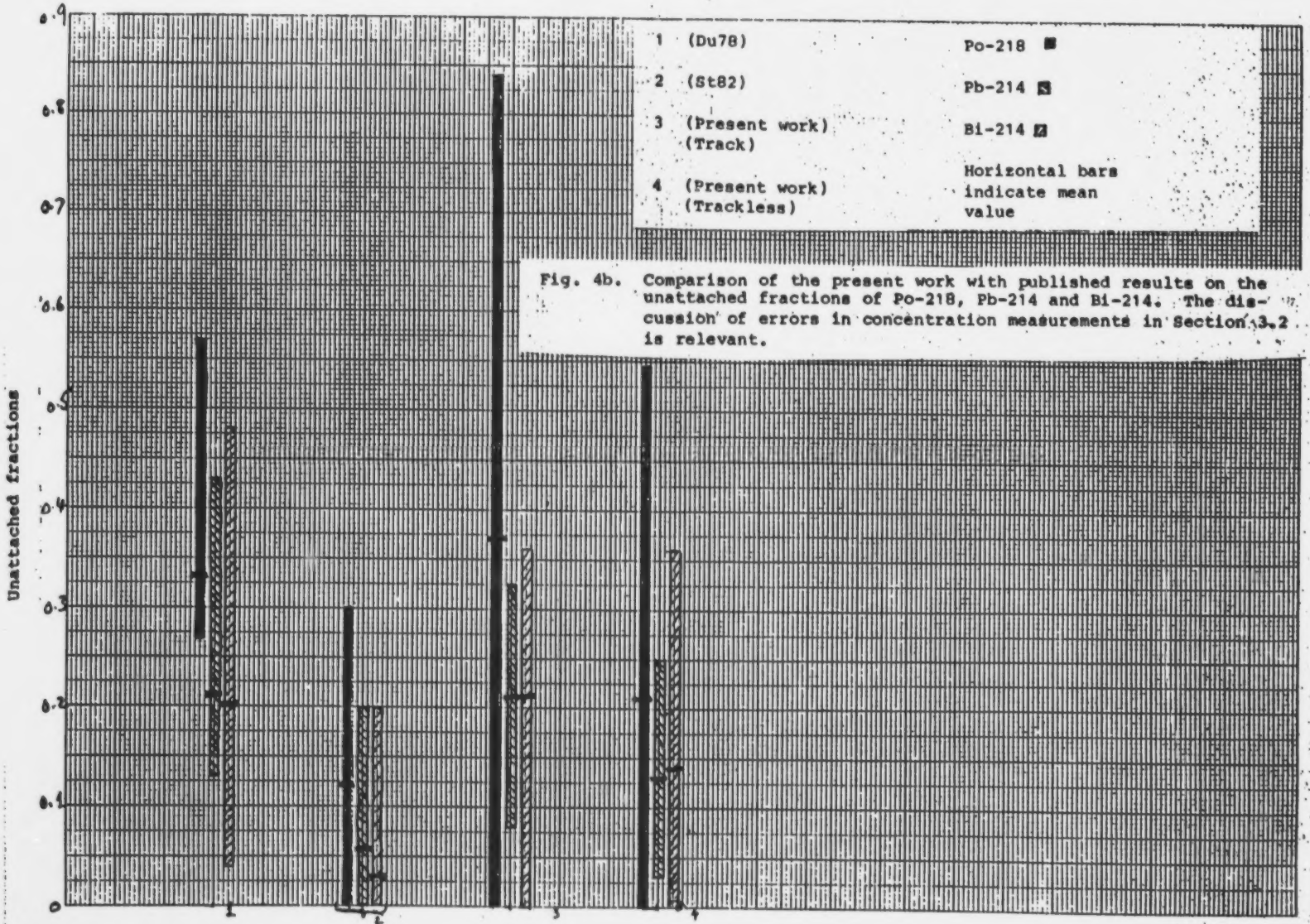


Fig. 4b. Comparison of the present work with published results on the unattached fractions of Po-218, Pb-214 and Bi-214. The discussion of errors in concentration measurements in Section 3.2 is relevant.

Figure 4b.

1. (Du78) The indicated range refers to measurements made by diffusion tube, diffusion batteries (with 60 and 24 channels) wire screens (49 and 19.4 mesch/cm) and Mercer Impactor. Aerosol concentration ~ 15000/cm^3.
2. (St82) Results of 33 measurements in Norwegian non-uranium mines.
3. (Present work - track) Aerosol concentrations 30,000-80,000/cm^3 in track mine.
4. (Present work - trackless) Aerosol concentrations 90,000-170,000/cm^3.

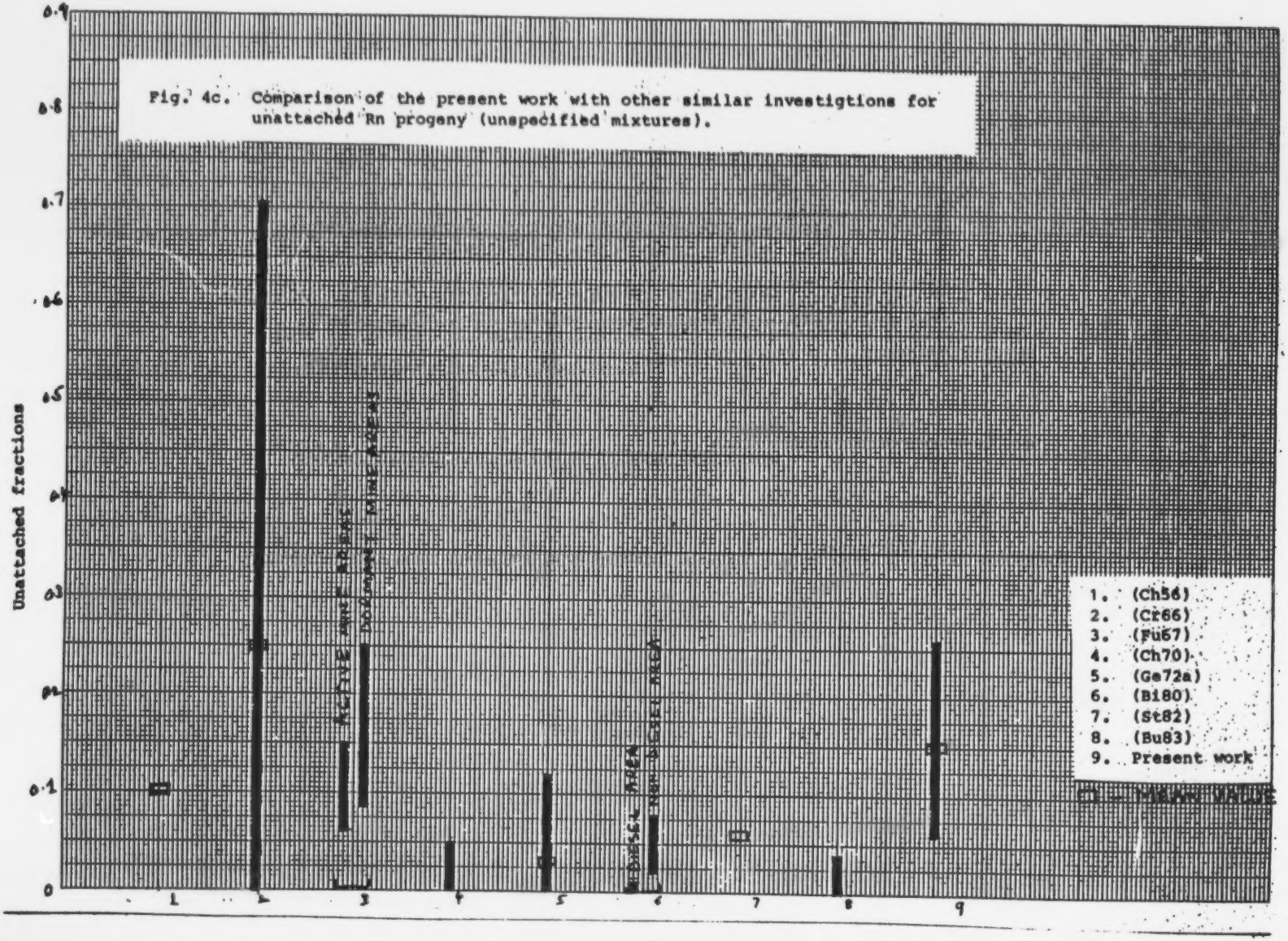


Fig. 4c. Comparison of the present work with other similar investigtions for unattached Rn progeny (unspecified mixtures).

Figure 4c

1. (Ch56) Measured by diffusion samples in 100% R.H.
2. (Cr66) Measured by 3.7 dia, 60 cm long diffusion tube at 60-90% R.H. Inadequate discrimination against attached daughters.
3. (Fu67) Diffusion sampler method.
4. (Ch70) Measured by electrostatic sampler at R.H. >99% and aerosol concentration ~ $5 \times 10^4/cm^3$.
5. (Ge72a) Measured by diffusion sample at R.H. = 91-97%. Aerosol concentrations = $3 \times 10^3 - 10^7/cm^3$.
6. (Bi80) Average of both wire screen and diffusion sampler measurements.
7. (St82) 68.5 mesh/cm wire screen with collection efficiency 86% used.
8. (Bu83) 60 mesh/cm wire screen used. Collection efficiency 76%.
9. (Present work) 60 mesh/cm wire screen used. Collection efficiency calculated separatly for each sample from the flow velocity.

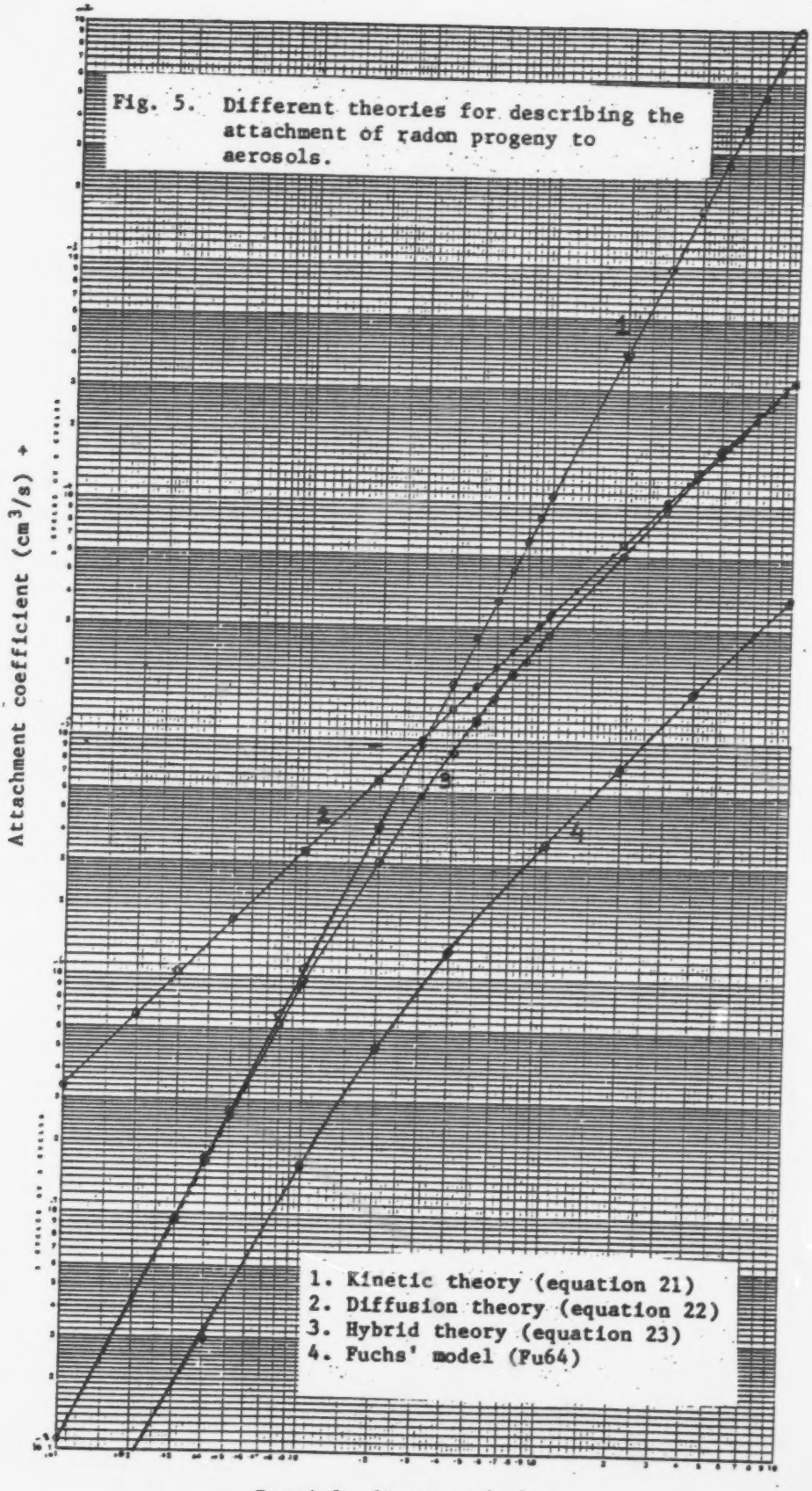

Attachment coefficient (cm³/s) →
Particle diameter (μm) →
1. Kinetic theory (equation 21)
2. Diffusion theory (equation 22)
3. Hybrid theory (equation 23)
4. Fuchs' model (Fu64)

Fig. 5. Different theories for describing the attachment of radon progeny to aerosols.

APPENDIX A

Sample Calculations for Paired t-Test

Track Mine Data: Jan 30 - Feb 1

1. Po-218

Ref. concns.	Buf. concns.	Difference (Ref - Buf)
30.6	29	1.6
24	18.6	5.4
23.5	18.33	5.17
29.2	28	1.2
35.14	20.4	14.74
42.9	36.2	6.7
67.7	69.8	-2.1
71.1	39.6	31.5
75	57	18
		$\bar{x} = 9.13$
		$\sigma_{n-1} = 10.56$

Null hypothesis: $\mu = a$; $a = 0$ i.e. there is no difference between the ref. and buf. concentrations.

$$t = \frac{\bar{x} - a}{\sigma_{n-1}/\sqrt{n}} = \frac{9.13}{10.56/\sqrt{9}} = 2.59$$

- At 0.05 level of significance, $t_{0.05,8} = 1.86$

  Since $t > t_{0.05,8}$, the hypothesis is rejected at 0.05 level of significance.

- At 0.01 level of significance, $t_{0.01,8} = 2.896$

  Since $t < t_{0.01,8}$, the hypothesis is accepted at 0.01 level of significance.

2. Pb-214

Ref. concns.	Buf. concns.	Difference (Ref-Buf)
13.9	11.4	2.5
13.4	11.05	2.35
10.94	9.44	1.5
14.6	14	0.6
17.5	16.5	1.0
23.9	21.5	2.4
50.8	45.6	5.2
54.3	52.1	2.2
51.5	43.8	7.7

$\bar{x} = 2.83$

$\sigma_{n-1} = 2.24$

Null hypothesis: $\mu = a$; $a = o$

$$t = \frac{\bar{x} - a}{\sigma_{n-1}/\sqrt{n}} = \frac{2.83}{2.24/\sqrt{9}} = 3.79$$

- At 0.05 level of significance, $t_{0.05,8} = 1.86$

  Since $t > t_{0.05,8}$, the hypothesis is rejected at 0.05 level of significance.

- At 0.01 level of significance, $t_{0.1,8} = 2.896$

  Since $t > t_{0.01,8}$, the hypothesis is rejected at 0.01 level of significance.

APPENDIX B

Summary of the Mine Measurement Results

Radionuclide concentrations and Rn/Tn Working Levels

- Tables 13-15

Unattached fractions, aerosol and activity size distributions

- Tables 16 and 17

TABLE 13

Concentrations and Working Levels of Radon/Thoron Progeny (Rio Algom)

Date	Time	Concentrations (pCi/L)					Concentration Ratios	Age of air (min) (approximate, from (Ev69))	Working Level* (from measured concentrations		Working Level** (Grab sample)		
		^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	^{212}Bi			RnWL	TnWL	Time	RnWL	TnWL
Jan 29	9.00	25.8	11.6	5.9	1.25	2.02	100:45:22:5	30	0.11	0.15	11.25	0.09	0.12
	9.15	22.6	8.4	8.3	1.42	4.55	100:37:37:6	25	0.10	0.17	13.40	0.08	0.09
	11.35	24.4	10.5	4.7	1.02		100:43:19:4	30	0.10	0.12			
Jan 30	8.45	21.2	8.5	4.5	1.09	0.39	100:40:21:5	25	0.08	0.13	10.10	0.11	0.15
	9.00	13	8	7.9	1.13	0.35	100:61:61:9	40	0.08	0.14	12.25	0.09	0.12
	10.50	30.6	13.9	7.3	1.34		100:45:24:4	30	0.13	0.16			
	11.25	24	13.4	7.8	1.29		100:56:32:5	35	0.12	0.16			
	13.00	23.5	10.9	6	0.99		100:46:25:4	30	0.10	0.12			
Jan 31	8.55	24.4	12.9	7.8	1.21	0.48	100:53:32:5	40	0.12	0.15	11.20	0.14	0.17
	9.10	16.5	11	10.3	1.25	0.54	100:67:62:7	45	0.11	0.15	13.35	0.20	0.20
	11.00	29.2	14.6	8.2	1.2		100:50:28:4	35	0.13	0.15			
	11.35	35.1	17.5	9.2	1.49		100:50:26:4	35	0.16	0.18			
	13.20	42.9	23.9	13.06	1.78		100:56:30:4	35	0.21	0.22			
Feb 1	9.25	58	44	35	3.25	1.87	100:76:60:6	60	0.41	0.40	11.50	0.55	0.49
	9.40	40.4	34.4	47†	3.55	7.55	-	--	0.39	0.44	14.05	0.48	0.35
	11.30	67.7	50.8	41.6	3.24		100:75:61:5	60	0.48	0.40			
	12.05	71.1	54.3	44.1	3.36		100:76:62:5	60	0.51	0.41			
	13.50	75	51.5	39.6	2.91		100:69:53:4	55	0.49	0.36			

* Calculated as: $RnWL = \frac{1.03\ C_{218_{Po}} + 5.07\ C_{214_{Pb}} + 3.73\ C_{214_{Bi}}}{100}$

$TnWL = \frac{123.19\ C_{212_{Pb}}}{1000}$ (The second term, $0.13\ C_{212_{Bi}}$, in the TnWL formula is ignored because the concentration of ^{212}Bi could not be measured with acceptable accuracy.)

** Calculated as: $RnWL = \frac{I\ (2\text{-}7)}{50 \times 235 \times V \times \eta}$

$TnWL = \frac{I\ (340\text{-}350)}{100 \times 13 \times V \times \eta}$ (All terms defined in the text)

† Physically impossible situation. Data ignored.

TABLE 14

Concentrations and Working Levels of Radon/Thoron Progeny (Denison)

Date	Time	Concentrations (pCi/L)					Concentration Ratios	Age of air (min) (approximate, from (Ev69))	Working Level* (from measured concentrations		Working Level** (Grab sample)		
		^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	^{212}Bi			RnWL	TnWL	Time	RnWL	TnWL
Feb 4	8.40	72.2	36.3	24.4	2.41	3.25	100:50:34:3	35	0.35	0.30	11.05	0.36	--
	8.55	52.6	25.2†	28.6	2.27	1.84	--	--	0.29	0.28			
	10.45	66.2	38.3	25.3	2.2		100:58:38:3	40	0.36	0.27			
	11.20	61.5	38.1	25.6	2.4		100:62:42:4	40	0.35	0.30			
	13.00	84.2	47.8	15.5	2.2		100:57:18:3	35	0.39	0.27			
Feb 5	8.40	21.7†	41.3	37.5	1.87	-2.2†	--	--	0.37	0.23	10.00	0.24	0.21
	10.40	47.5	28.5	19.3	1.67		100:60:41:3	45	0.26	0.21	12.15	0.29	0.22
	11.15	54.9	27.9	16.7	1.66		100:51:30:3	35	0.26	0.20			
	13.05	62.7	30.8	18.3	1.71		100:49:29:3	30	0.29	0.21			
Feb 6	9.00	53.4	30.5	20	1.72	2.78	100:57:37:3	40	0.28	0.21	11.25	0.31	0.20
	9.15	32.3	18.7†	25.3	2.04	7.9	--	--	0.20	0.25	13.40	0.31	0.19
	11.05	61.6	34	23	1.66		100:55:37:3	40	0.32	0.20			
	11.40	51	32.6	23.6	1.52		100:64:46:3	45	0.31	0.19			
	13.25	57.5	32.4	23.3	1.87		100:56:40:3	40	0.31	0.23			

* Explained in the footnote to Table 13

† Physically impossible situations. Data ignored.

TABLE 15

Working Levels of Radon/Thoron Progeny and ^{212}Pb Concentrations Obtained by One-Count Method[1] (Denison)

Date	Time	RnWL	TnWL	^{212}Pb concentration[2] (pCi/L)
	8.40	—	0.22[3]	1.8
	8.55	—	0.22[3]	1.8
	9.10	0.37	—	-
	9.20	0.36	—	-
	9.40	0.33	—	-
	9.50	0.30	—	-
	10.10	0.33	—	-
Feb 7	10.20	0.32	—	-
	10.40	0.28	—	-
	10.55	0.34	—	-
	12.05	—	0.20	1.7
	12.20	—	0.20	1.7
	12.40	—	0.20	1.7
	13.15	—	0.20	1.7
	13.40	—	0.19	1.6
	13.55	—	0.20	1.7
	8.30	—	0.20[3]	1.6
	8.45	0.27	—	-
	8.55	0.30	—	-
	9.15	0.28	—	-
Feb 8	9.35	0.28	—	-
	9.55	0.34	—	-
	12.00	—	0.20	1.7
	12.20	—	0.19	1.6
	13.30	—	0.19	1.6

[1] The method is described in Chapter 2.
[2] The calculation procedure for these is described in Chapter 2.
[3] Slightly overestimated due to modified counting interval in order to enable counting within the allowed working period.

TABLE 16

Unattached Fraction, Activity and Aerosol Size Distributions for Track-type Mine

Date	Unattached Fractions					Activity Size Distributions†					Aerosol Size Distributions		
	Time	^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	Time	^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	Time	Count Median dia. (μm)	GSD
Jan 29*	--	--	--	--	--	9.00	--	--	--	0.065 (2.69)	--	--	
	--	--	--	--	--	9.15	--	--	--	0.064 (2.42)	--	--	
Jan 30	10.50	0.10	0.35	0.36	0.24	8.45	0.053	0.047	0.043	0.057	9.40	0.051	2.34
	11.25	0.43	0.34	0.34	0.34		(2.21)	(1.59)	(2.43)	(2.30)	11.40	0.053	1.52
	13.00	0.42	0.26	0.33	0.10	9.00	0.063	0.056	0.059	0.072	12.50	0.050	2.68
							(2.62)	(1.51)	(1.34)	(2.47)	13.50	0.051	2.14
Jan 31	11.00	0.08	0.08	0.27	0.03	8.55	--	0.054	0.057	0.082	9.35	0.062	2.42
	11.35	0.78	0.11	-0.17	0.15			(2.16)	(2.40)	(2.55)	10.00	0.065	1.40
	13.20	0.29	0.19	0.15	0.25	9.10	--	0.044	0.060	0.10	11.50	0.058	2.19
								(2.47)	(2.19)	(1.75)	13.00	0.061	1.72
											14.05	0.072	2.56
Feb 1	11.30	-0.06	0.19	0.23	0.20	9.40	0.047	0.047	0.053	0.058	10.25	0.046	1.60
	12.05	0.84	0.08	0.23	0.20		(2.29)	(1.54)	(1.45)	(1.89)	12.20	0.050	1.76
	13.50	0.44	0.28	0.12	0.26						13.25	0.048	1.56

* Exact pump flow rates were not known for each sample. Most data had to be rejected because of unknown errors. Condensation nuclei counters malfunctioned. Aerosol concentration data were, therefore, also rejected.

† The listed values are for the median diameters (in μm) of the activity size distributions for specified radionuclides. The geometric standard deviations are given in brackets below each diameter.

TABLE 17

Unattached Fraction, Activity and Aerosol Size Distributions for Trackless Mine

Date	Unattached Fractions					Activity Size Distributions**					Aerosol Size Distributions		
	Time	^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	Time	^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	Time	Count Median dia. (μm)	GSD
Feb 4	10.45	0.26	0.13	0.02	0.08	8.40	0.084	0.091	0.096	--	9.30	0.088	1.84
	11.20	0.13	0.11	0.17	0.15		(2.06)	(1.48)	(2.09)		12.40	0.094	1.43
	13.00	0.30	0.25	0.36	0.29								
Feb 5	10.40	-0.02	0.11	0.24	0.11	8.40	--	0.053	0.078	0.092	9.20	0.070	1.15
	11.15	-0.02	0.04	0.10	-0.02			(2.76)	(2.50)	(1.29)	11.50	0.084	1.48
	13.05	0.30	0.12	-0.03	0.08						12.50	0.032	2.50
Feb 6	11.05	0.54	0.22	0.16	0.25	9.00	0.066	0.073	0.077	0.09	9.45	0.062	1.55
	11.40	-0.06	0.16	0.19	0.02		(2.40)	(1.81)	(1.75)	(2.23)	12.00	0.047	1.98
	1.25	0.48	0.03	0.07	0.14	9.15	0.069	--	0.089	0.10	13.05	0.076	1.41
							(1.29)		(1.56)	(2.68)			
		RnWL		Time			RnWL		Time				
Feb 7*	9.20	0.06		8.55	0.06	9.10	0.097	(1.84)	8.40	0.125			
	9.50	0.09		12.25	0.05	9.40	0.085	(1.86)		(1.68)			
	10.20	0.26		12.45	0.22	10.10	0.089	(2.55)	13.15	0.107			
	10.55	0.16		14.00	0.05	10.40	0.096	(1.81)		(1.65)			
									13.40	0.106			
										(1.62)			
Feb 8†	8.55	0.24		8.25	0.12	8.45	0.079	(1.65)	--	--	10.04	0.07	1.5
	9.25	0.10		12.00	0.22	9.15	0.089	(1.58)			10.20	0.07	1.43
	9.55	0.15		12.20	0.21								
				13.35	0.12								

* No suitable time slot was available to measure aerosol size distributions.
** Explained in footnotes to Table 16.
† Data for activity size distributions of ^{212}Pb had to be rejected because of pump failure.

APPENDIX C

Graphs for Aerosol Size Distribution Data

Track mine: Figs. 6-8

Trackless mine: Figs. 9-11

Aerosol Concentration Records for each Measurement Day

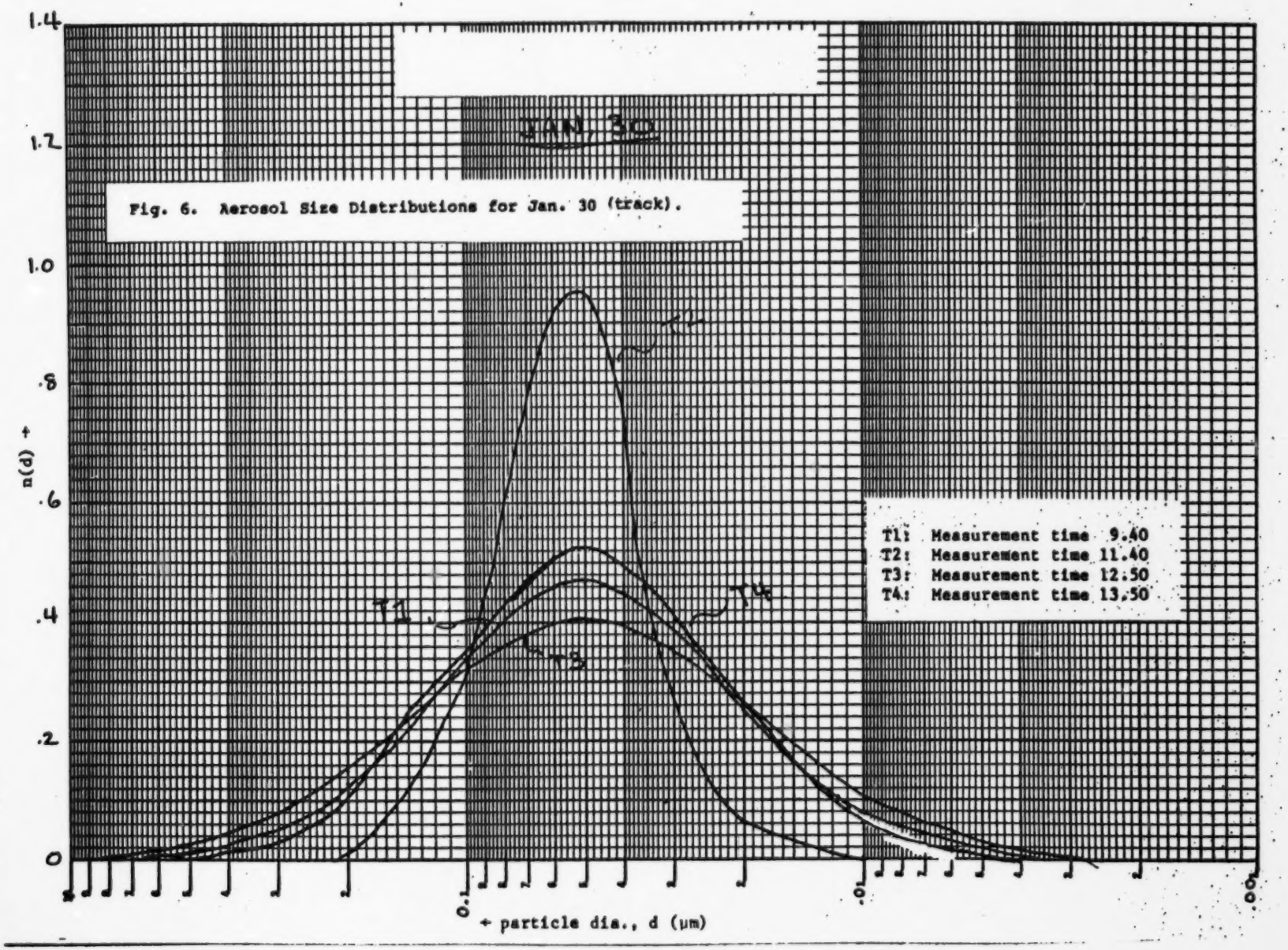
Track mine: Figs. 13-15

Trackless mine: Figs. 16-20

Activity Size Distribution Plots

Track mine: Figs. 21-24

Trackless mine: Figs. 25-29


JAN. 30
Fig. 6. Aerosol Size Distributions for Jan. 30 (track).
1.4
1.2
1.0
.8
.6
.4
.2
0
n(d) →
T1
T2
T3
T4
T1: Measurement time 9.40
T2: Measurement time 11.40
T3: Measurement time 12.50
T4: Measurement time 13.50
0.
0.
00.
→ particle dia., d (μm)

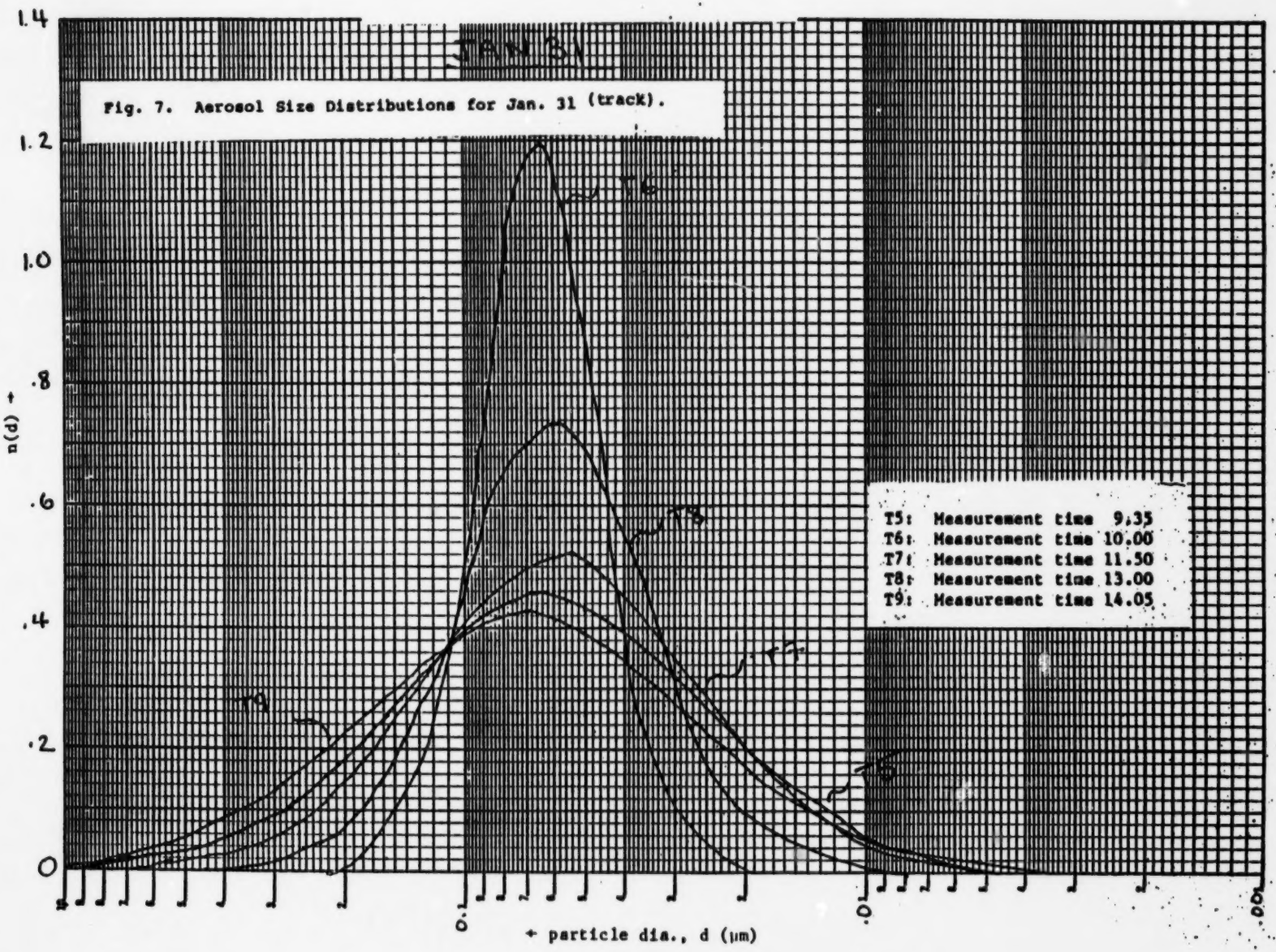
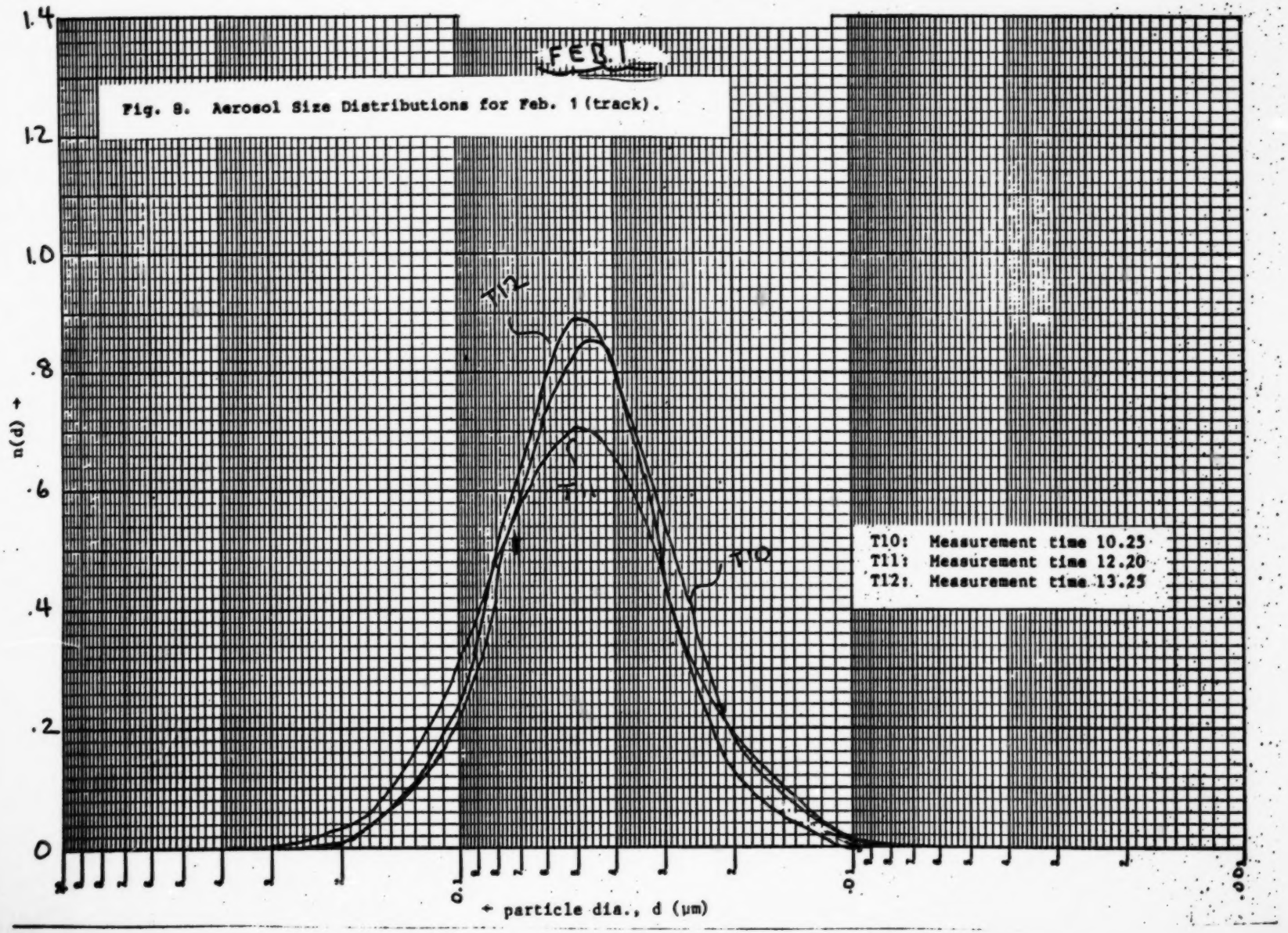


Fig. 7. Aerosol Size Distributions for Jan. 31 (track).


FEB. 1
Fig. 8. Aerosol Size Distributions for Feb. 1 (track).
1.4
1.2
1.0
.8
.6
.4
.2
0
n(d) →
T12
T11
T10
T10: Measurement time 10.25
T11: Measurement time 12.20
T12: Measurement time 13.25
0.1
1
10
100
→ particle dia., d (μm)

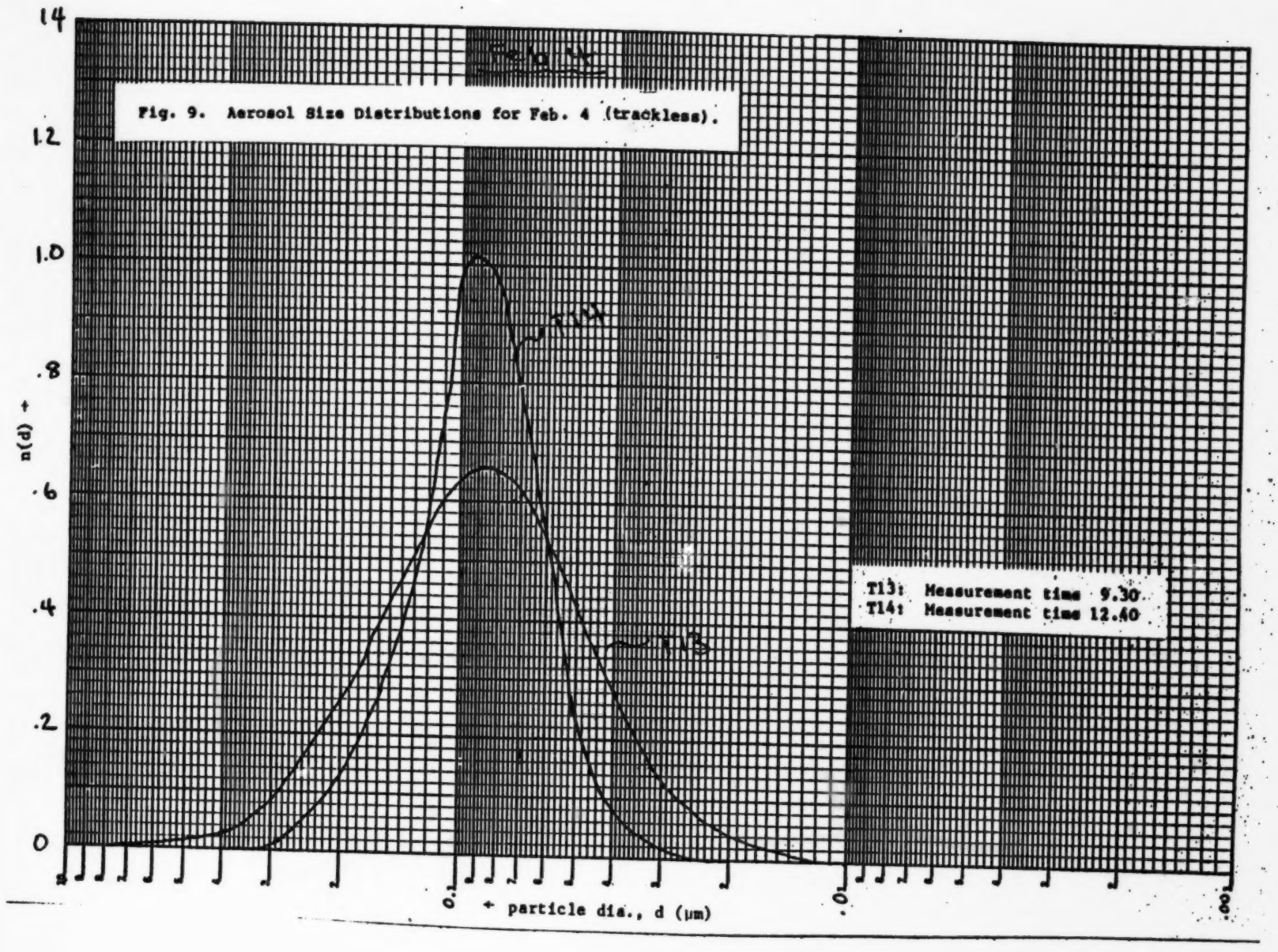


Fig. 9. Aerosol Size Distributions for Feb. 4 (trackless).
T13: Measurement time 9.30
T14: Measurement time 12.40
n(d) →
→ particle dia., d (μm)
14
1.2
1.0
.8
.6
.4
.2
0

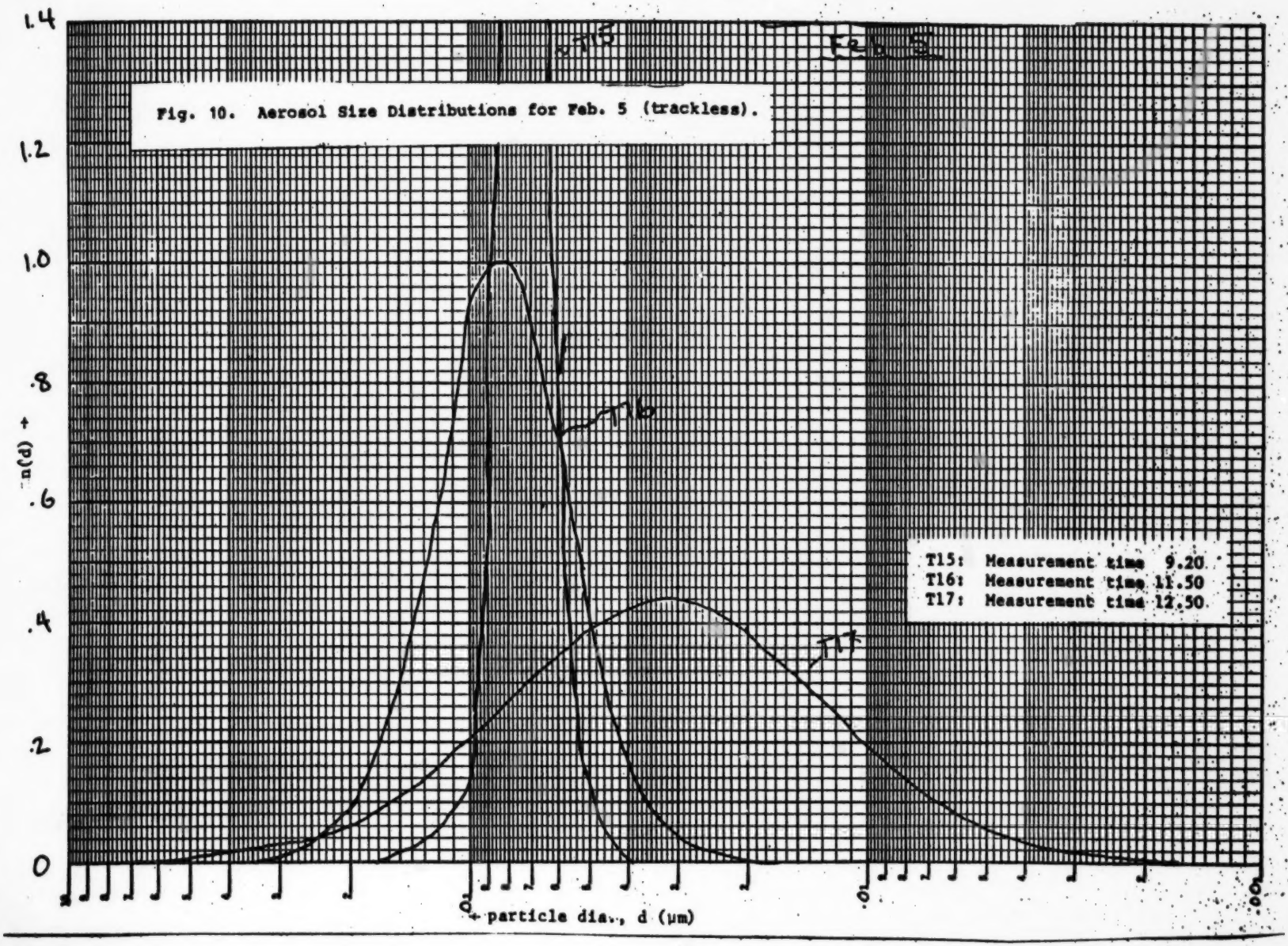


Fig. 10. Aerosol Size Distributions for Feb. 5 (trackless).
T15
T16
T17
T15: Measurement time 9.20
T16: Measurement time 11.50
T17: Measurement time 12.50
n(d)
particle dia., d (μm)
1.4
1.2
1.0
.8
.6
.4
.2
0
.01
.001

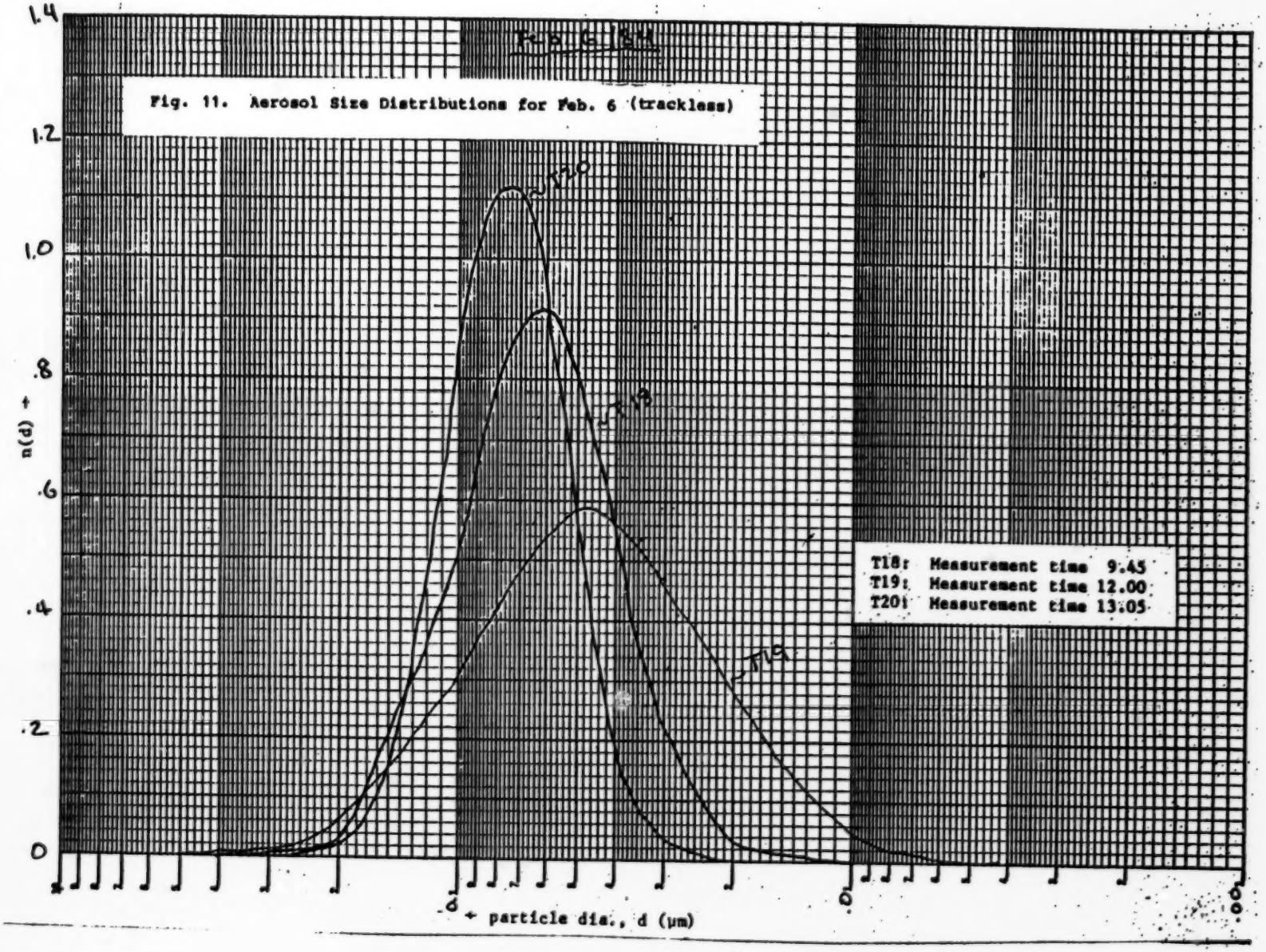


Fig. 11. Aerosol Size Distributions for Feb. 6 (trackless)

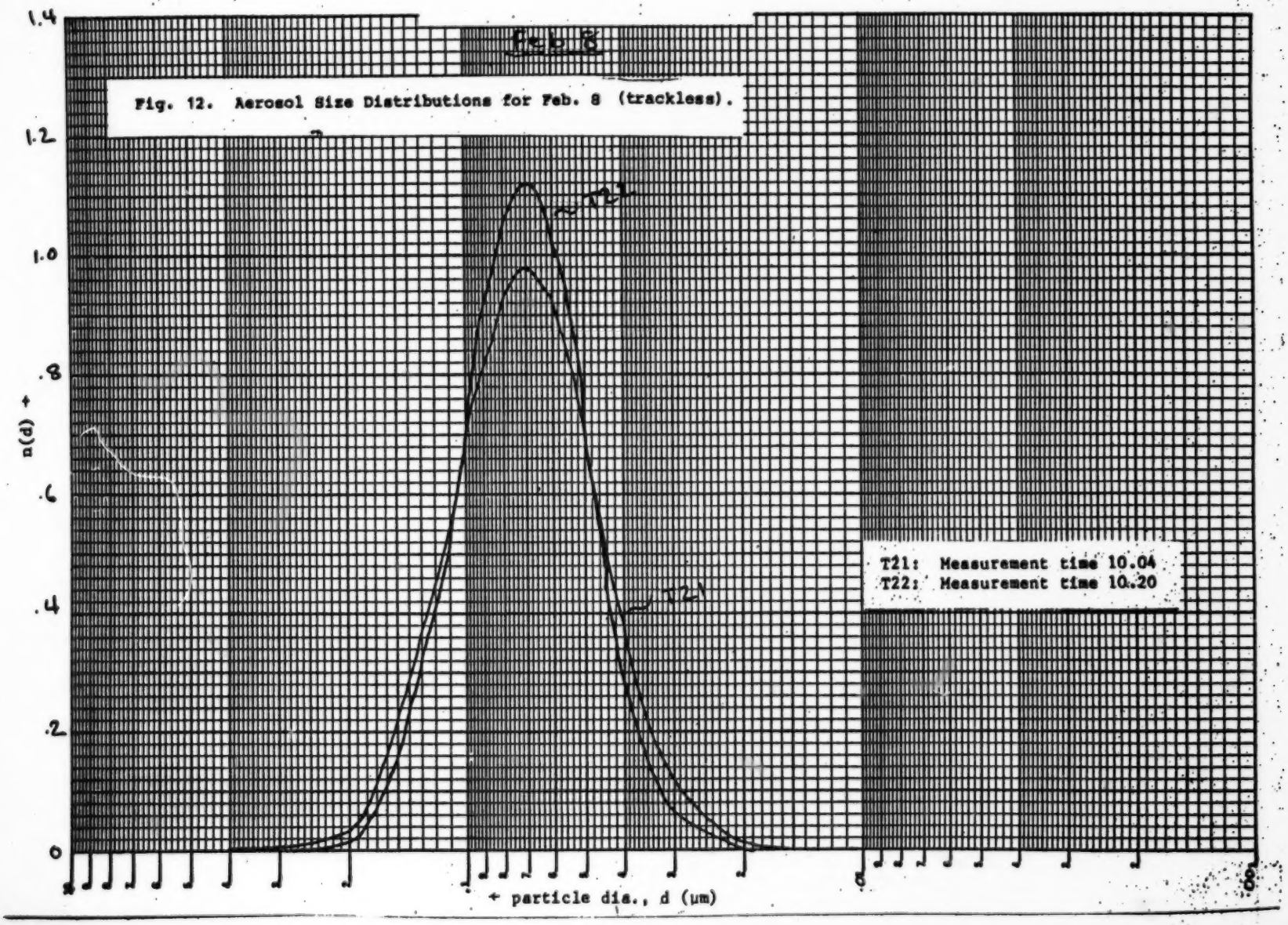


Fig. 12. Aerosol Size Distributions for Feb. 8 (trackless).

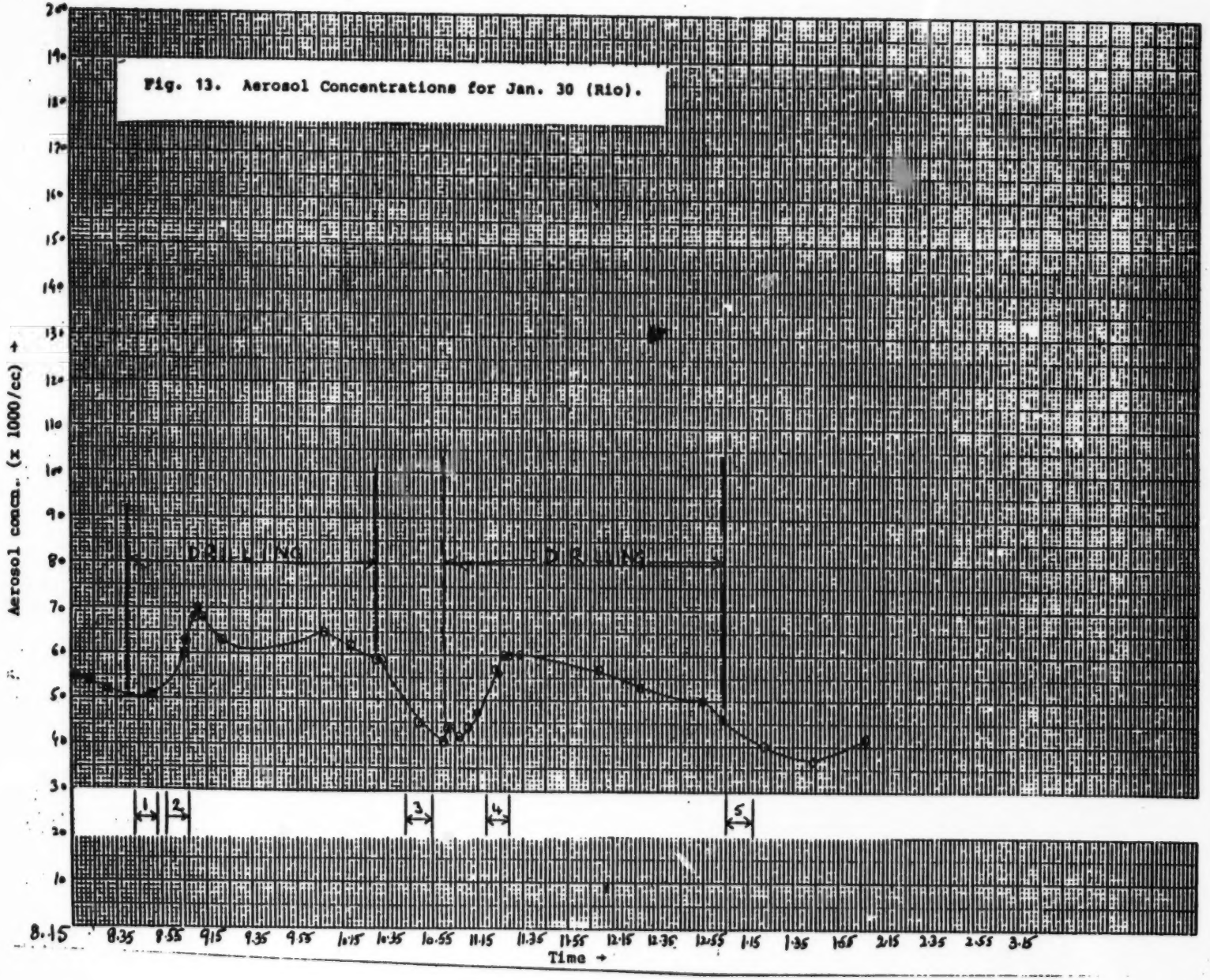


Fig. 13. Aerosol Concentrations for Jan. 30 (Rio).

Legend for Figure 13

1. Diffusion Battery Sample #1.
2. Diffusion Battery Sample #2.
3. Unattached Fraction Sample #1.
4. Unattached Fraction Sample #2.
5. Unattached Fraction Sample #3 .

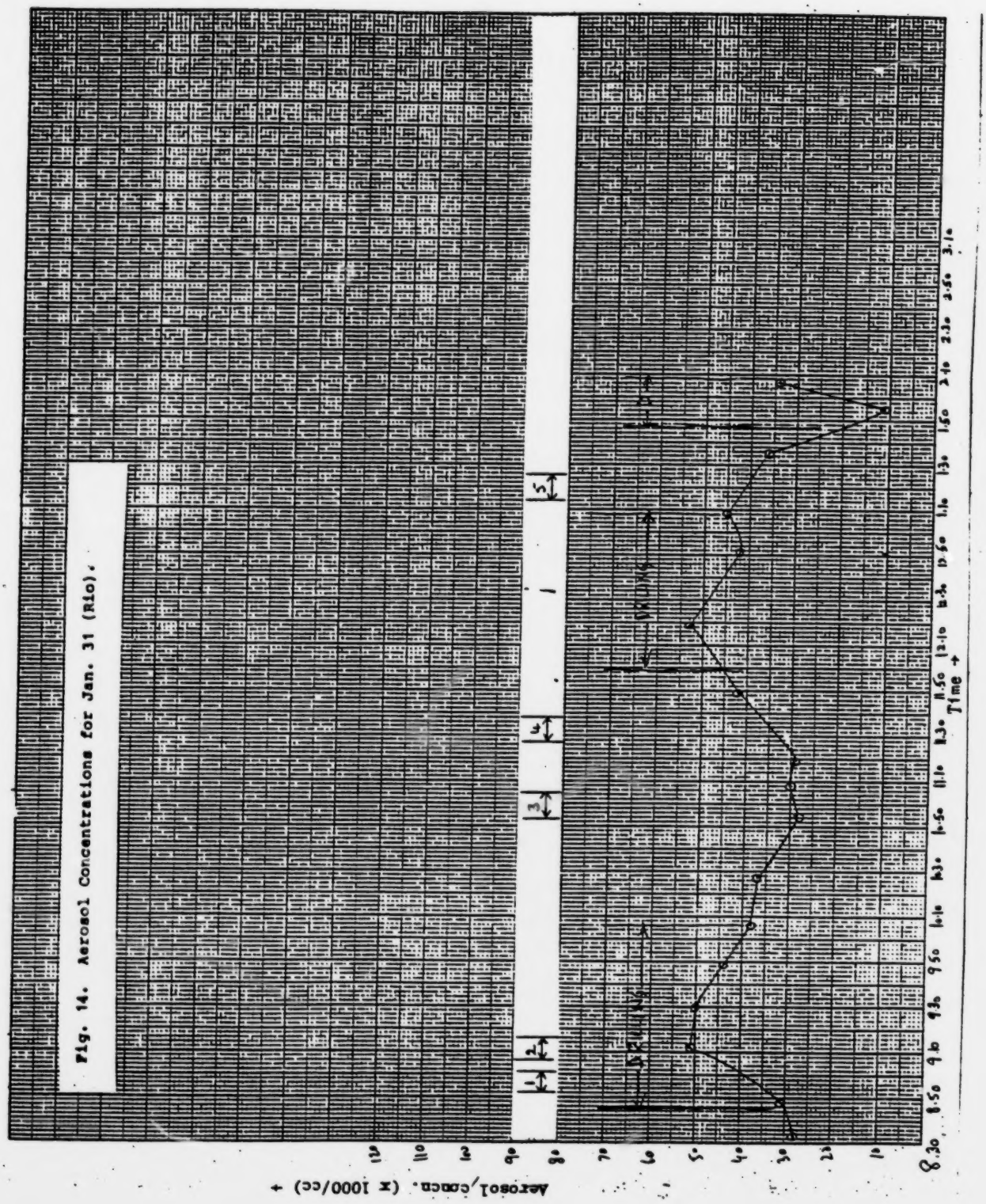


Fig. 14. Aerosol Concentrations for Jan. 31 (Rio).

Legend for Figure 14

1. Diffusion Battery Sample #1.
2. Diffusion Battery Sample #2.
3. Unattached Fraction Sample #1.
4. Unattached Fraction Sample #2.
5. Unattached Fraction Sample #3.

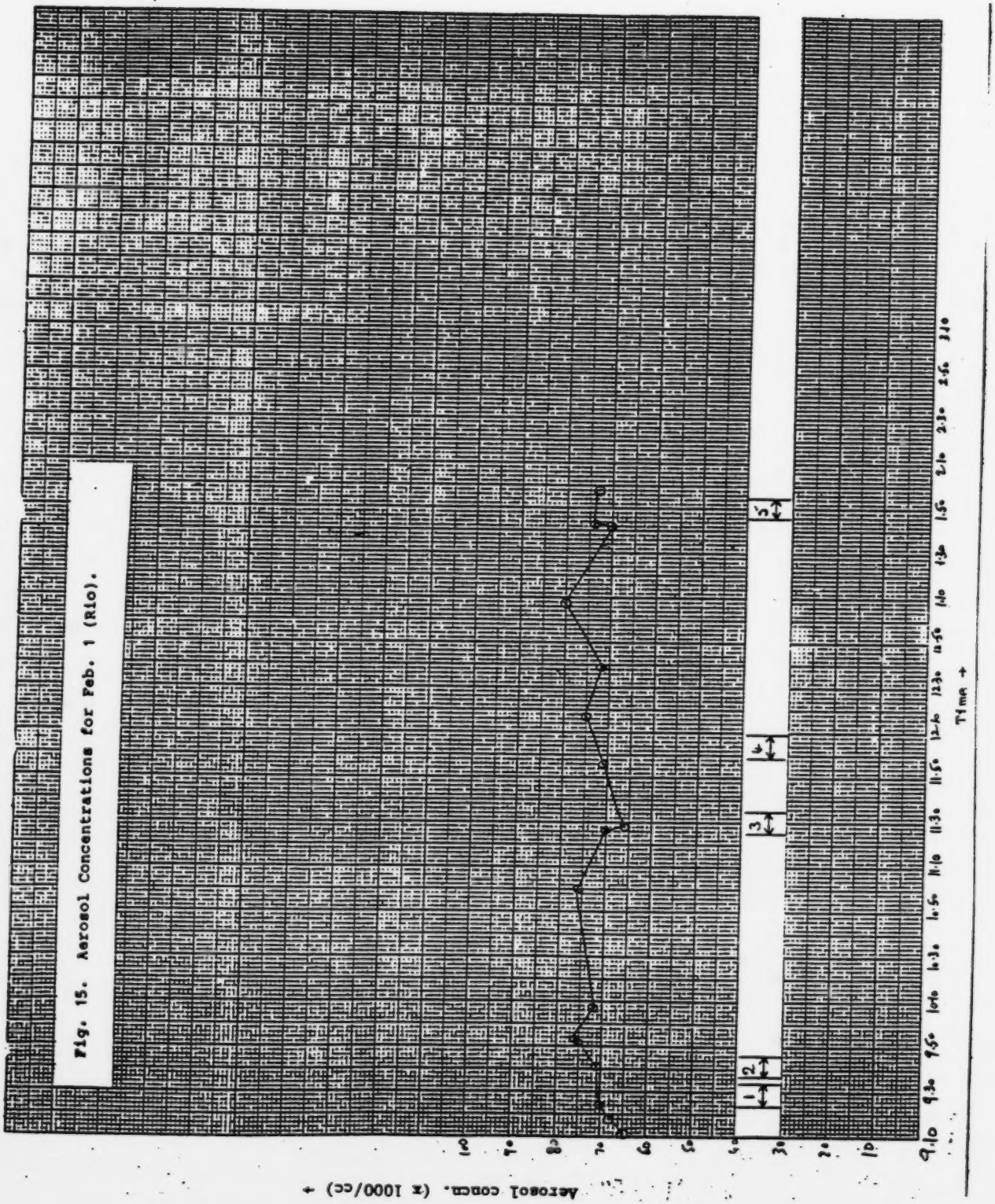


Fig. 15. Aerosol Concentrations for Feb. 1 (Rio).

Legend for Figure 15

1. Diffusion Battery Sample #1.
2. Diffusion Battery Sample #2.
3. Unattached Fraction Sample #1.
4. Unattached Fraction Sample #2.
5. Unattached Fraction Sample #3.

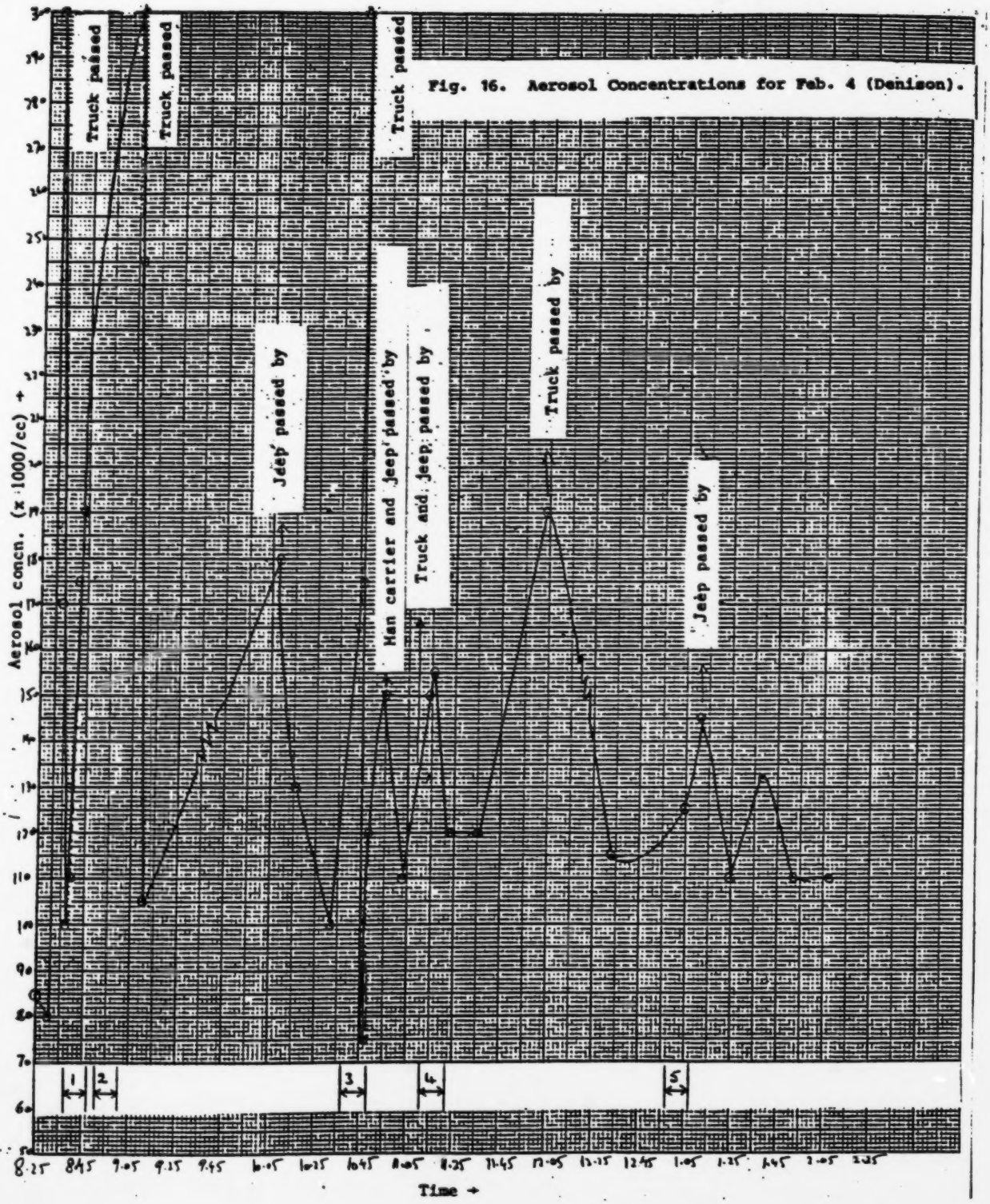


Fig. 16. Aerosol Concentrations for Feb. 4 (Denison).

Legend for Figure 16

1. Diffusion Battery Sample #1.
2. Diffusion Battery Sample #2.
3. Unattached Fraction Sample #1.
4. Unattached Fraction Sample #2.
5. Unattached Fraction Sample #3 .

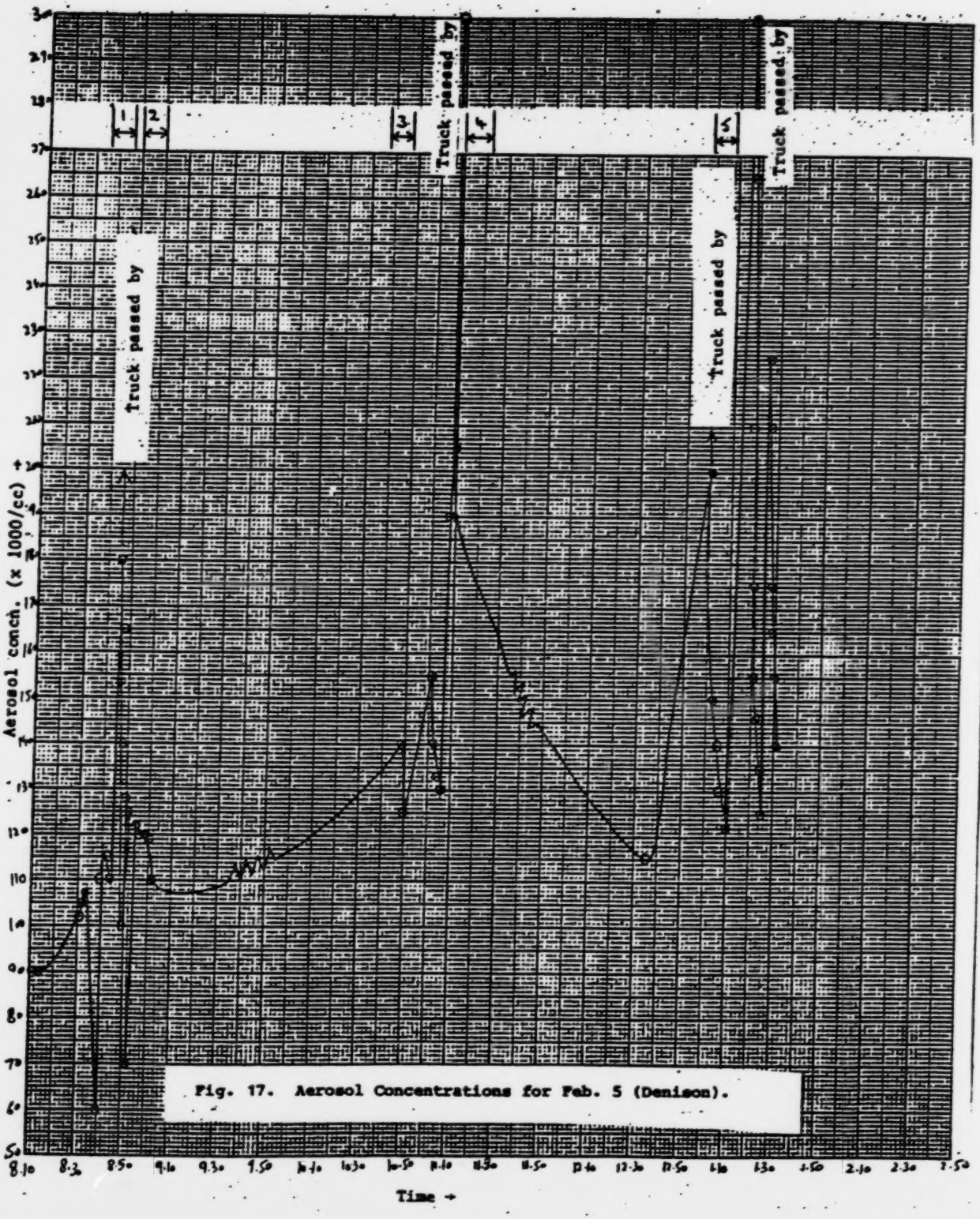


Fig. 17. Aerosol Concentrations for Feb. 5 (Denison).

Legend for Figure 17

1. Diffusion Battery Sample #1.
2. Diffusion Battery Sample #2.
3. Unattached Fraction Sample #1.
4. Unattached Fraction Sample #2.
5. Unattached Fraction Sample #3 .

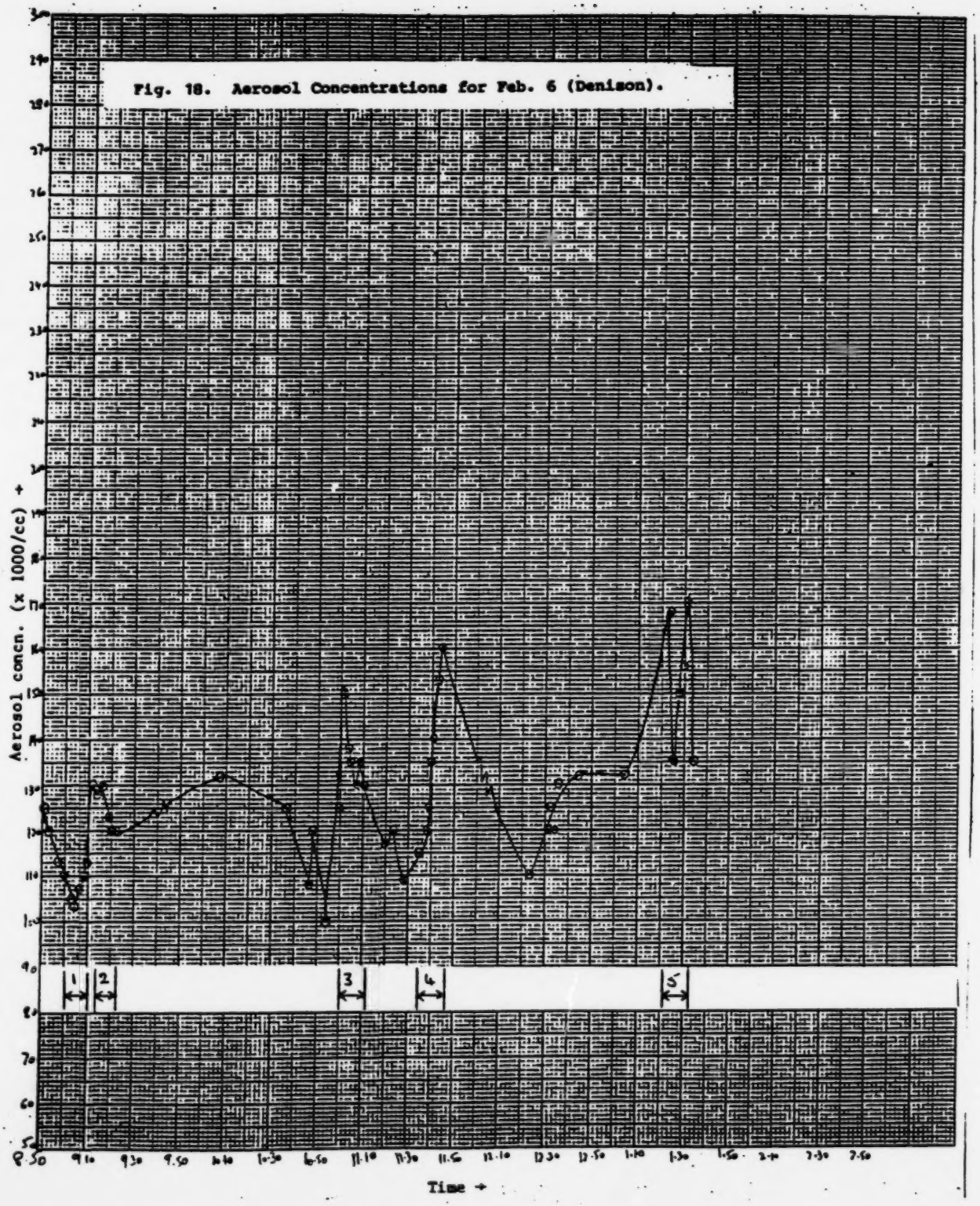


Fig. 18. Aerosol Concentrations for Feb. 6 (Denison).

Legend for Figure 18

1. Diffusion Battery Sample #1.
2. Diffusion Battery Sample #2.
3. Unattached Fraction Sample #1.
4. Unattached Fraction Sample #2.
5. Unattached Fraction Sample #3 .

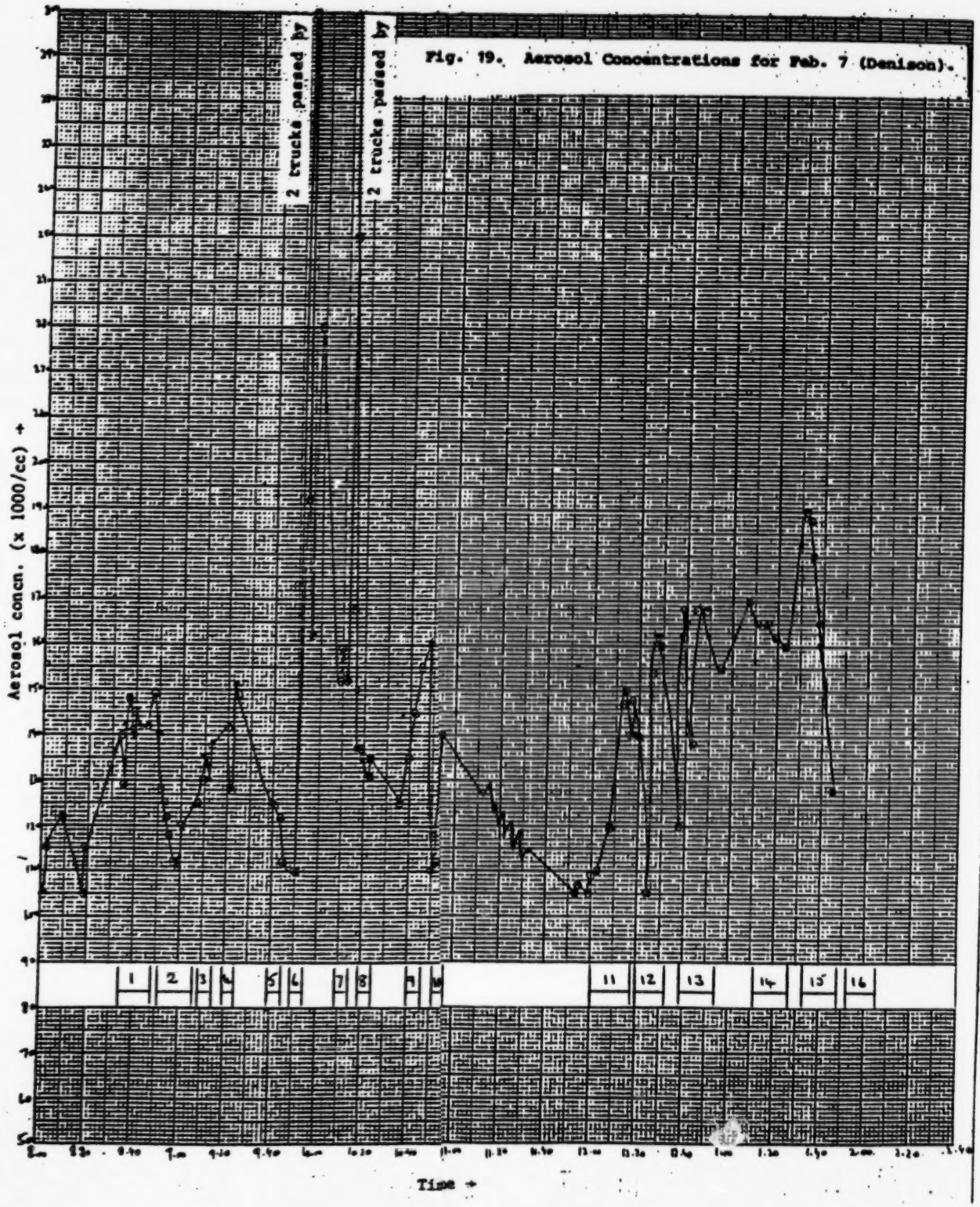


Fig. 19. Aerosol Concentrations for Feb. 7 (Denison).

Legend for Figure 19

1. Diffusion Battery Sample #1 ThB
2. Unattached Fraction Sample #1 ThB
3. Difusion Battery Sample #1 RnWL
4. Unattached Fraction Sample #1 RnWL
5. Diffusion Battery Sample #2 RnWL
6. Unattached Fraction Sample #2 RnWL
7. Diffusion Battery Sample #3 RnWL
8. Unattached Fraction Sample #3 RnWL
9. Diffusion Battery Sample #4 RnWL
10. Unattached Fraction Sample #4 RnWL
11. Diffusion Battery Sample #2 ThB
12. Unattached Fraction Sample #2 ThB
13. Unattached Fraction Sample #3 ThB
14. Diffusion Battery Sample #3 ThB
15. Diffusion Battery Sample #4 ThB
16. Unattached Fraction Sample #4 ThB

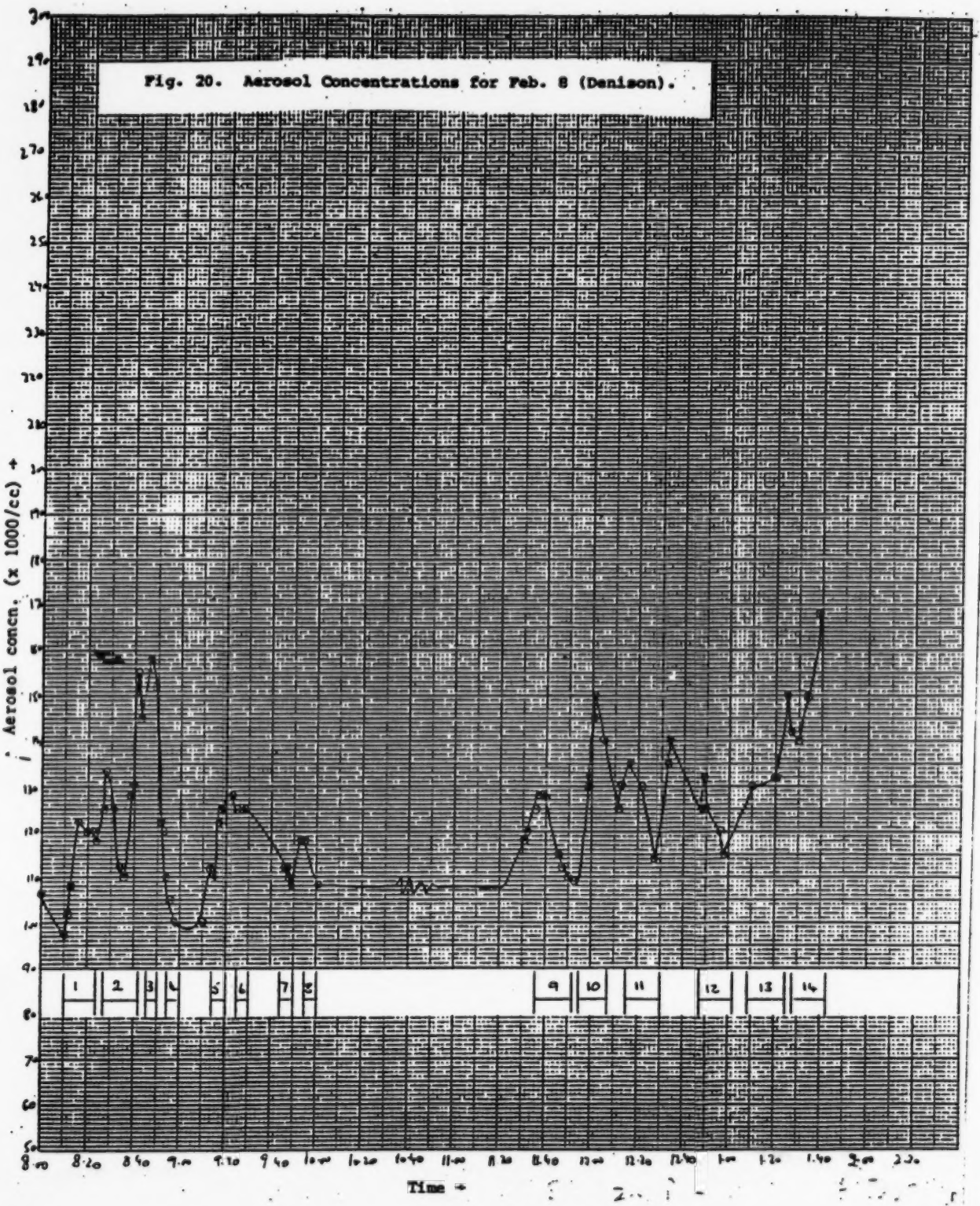


Fig. 20. Aerosol Concentrations for Feb. 8 (Denison).

Legend for Figure 20

1. Diffusion Battery Sample #1 ThB
2. Unattached Fraction Sample #1 ThB
3. Diffusion Battery Sample #1 RnWL
4. Unattached Fraction Sample #1 RnWL
5. Diffusion Battery Sample #2 RnWL
6. Unattached Fraction Sample #2 RnWL
7. Diffusion Battery Sample #3 RnWL
8. Unattached Fraction Sample #3 RnWL
9. Diffusion Battery Sample #2 ThB
10. Unattached Fraction Sample #2 ThB
11. Unattached Fraction Sample #3 ThB
12. Diffusion Battery Sample #3 ThB
13. Diffusion Battery Sample #4 ThB
14. Unattached Fraction Sample #4 ThB

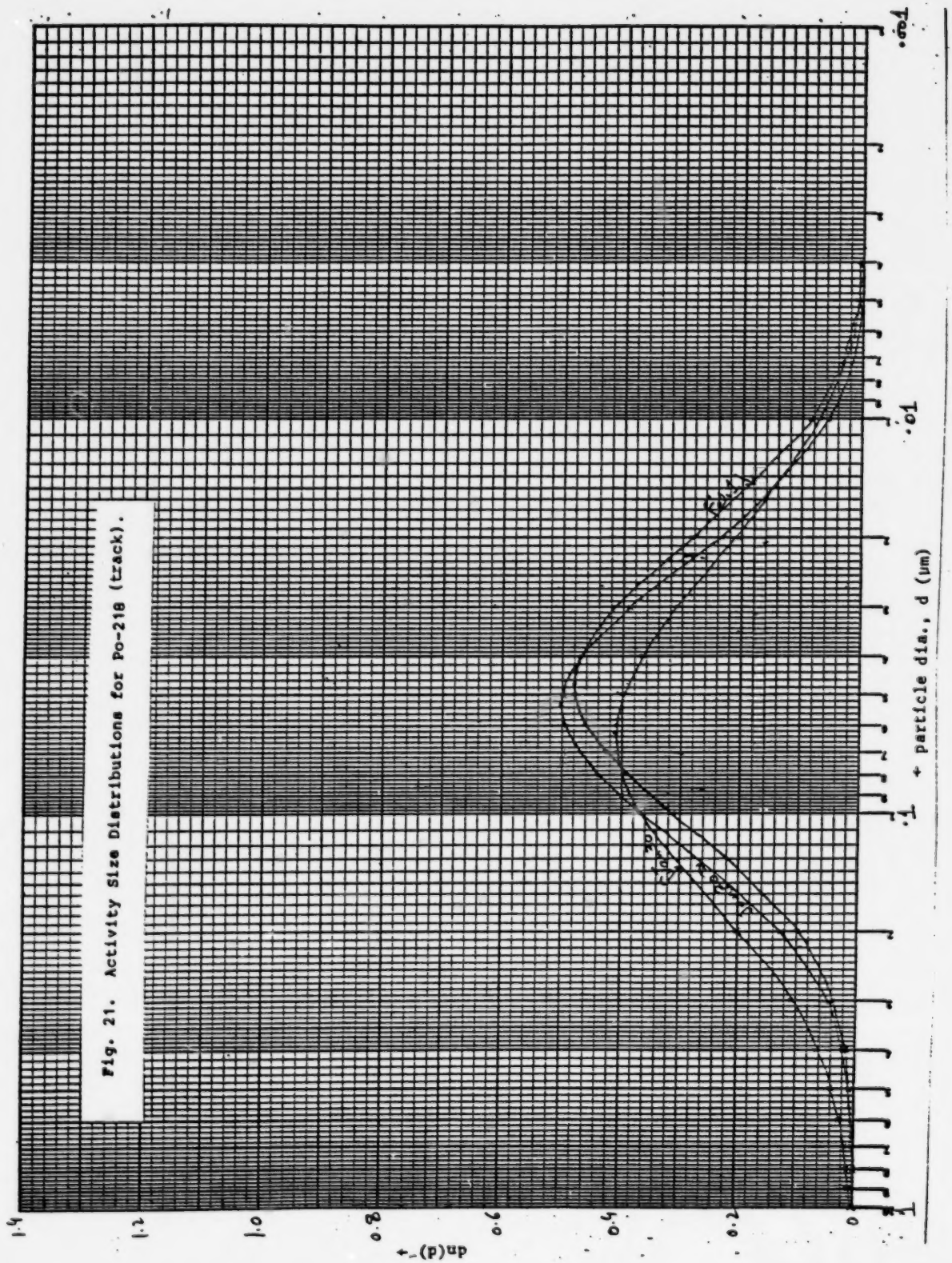


Fig. 21. Activity Size Distributions for Po-218 (track).

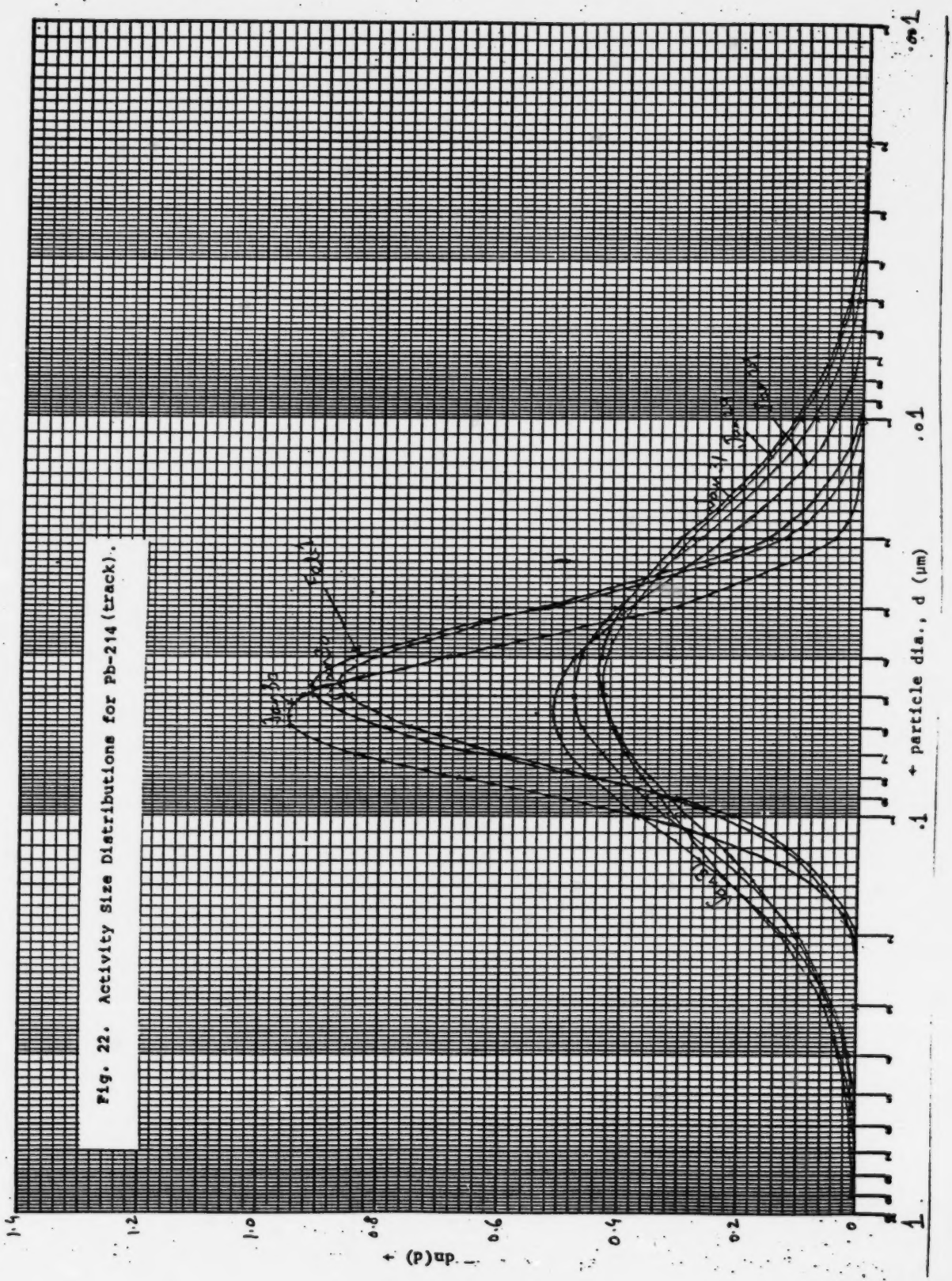


Fig. 22. Activity Size Distributions for Pb-214 (track).

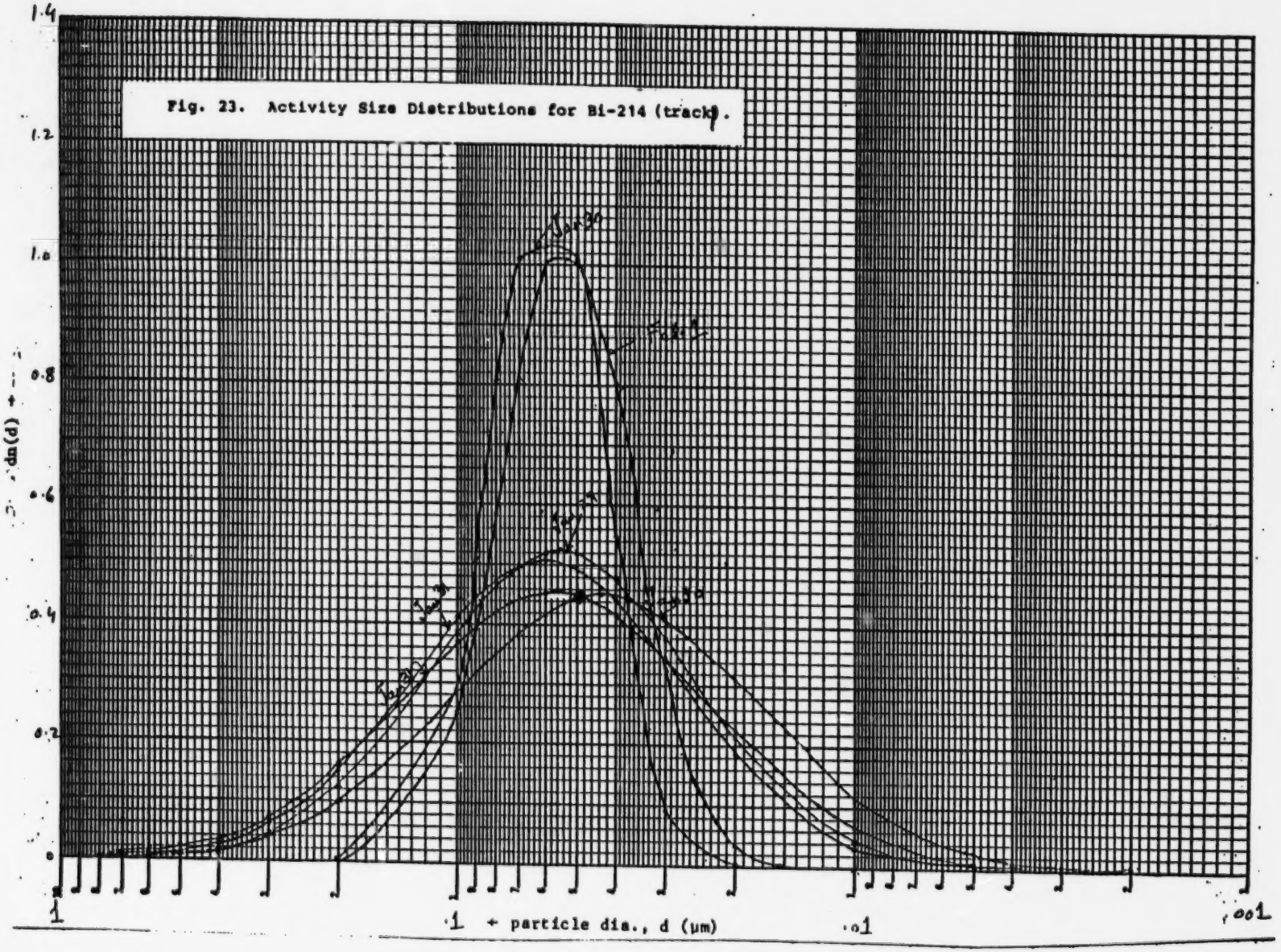


Fig. 23. Activity Size Distributions for Bi-214 (track).

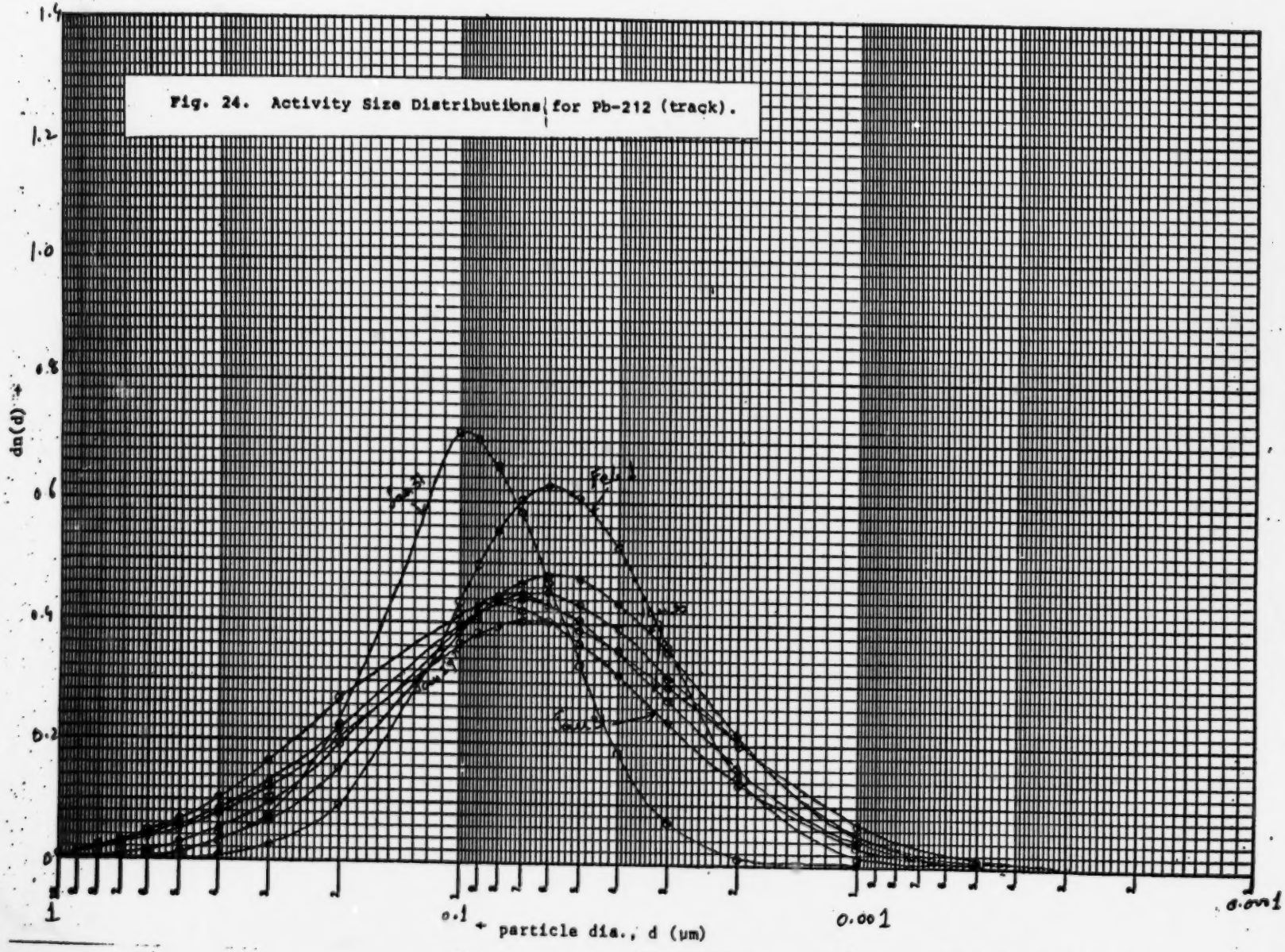


Fig. 24. Activity Size Distributions for Pb-212 (track).

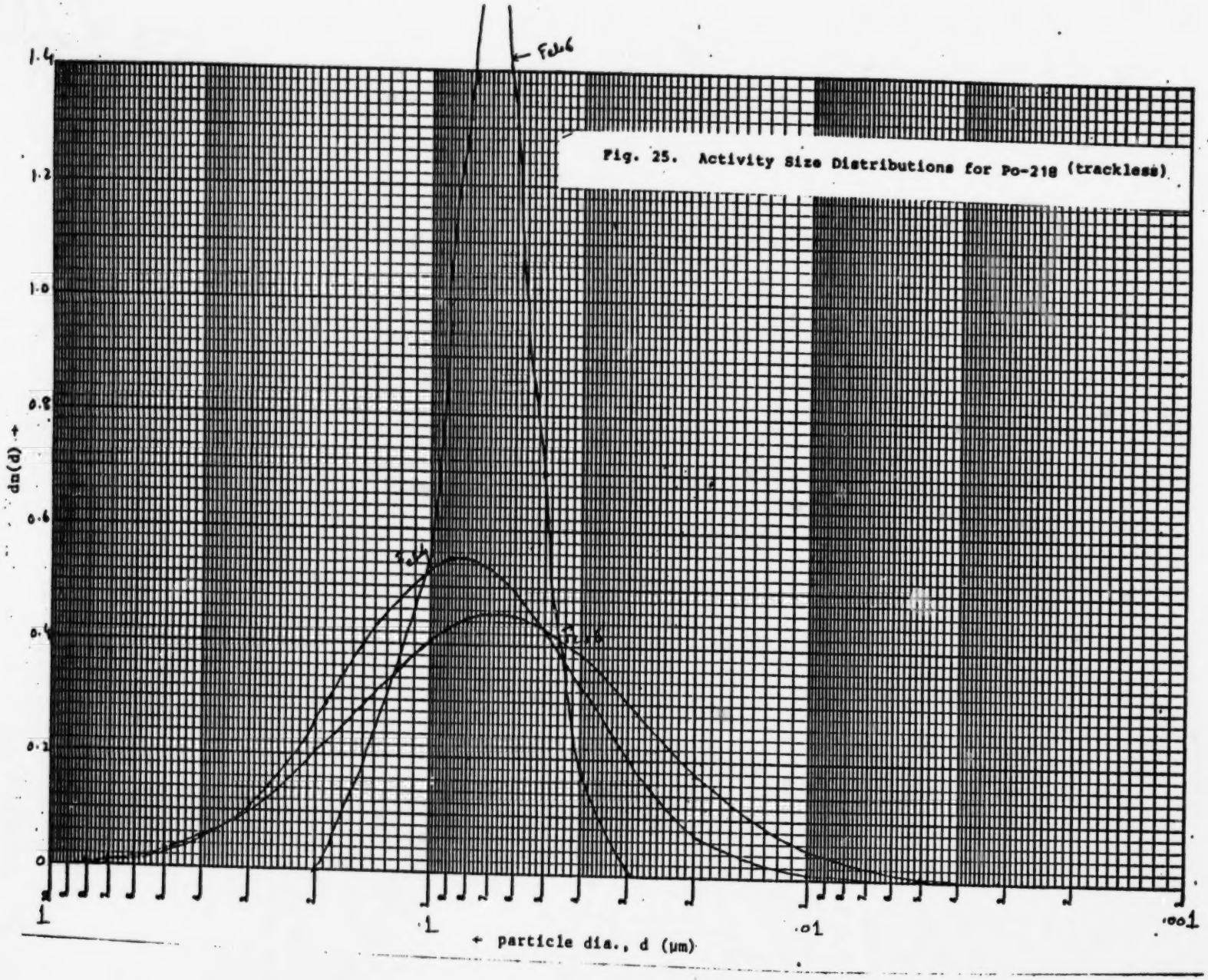


Fig. 25. Activity Size Distributions for Po-218 (trackless)
1.4
1.2
1.0
0.8
dn(d) →
0.6
0.4
0.2
0
1
.1
.01
.001
← particle dia., d (μm)

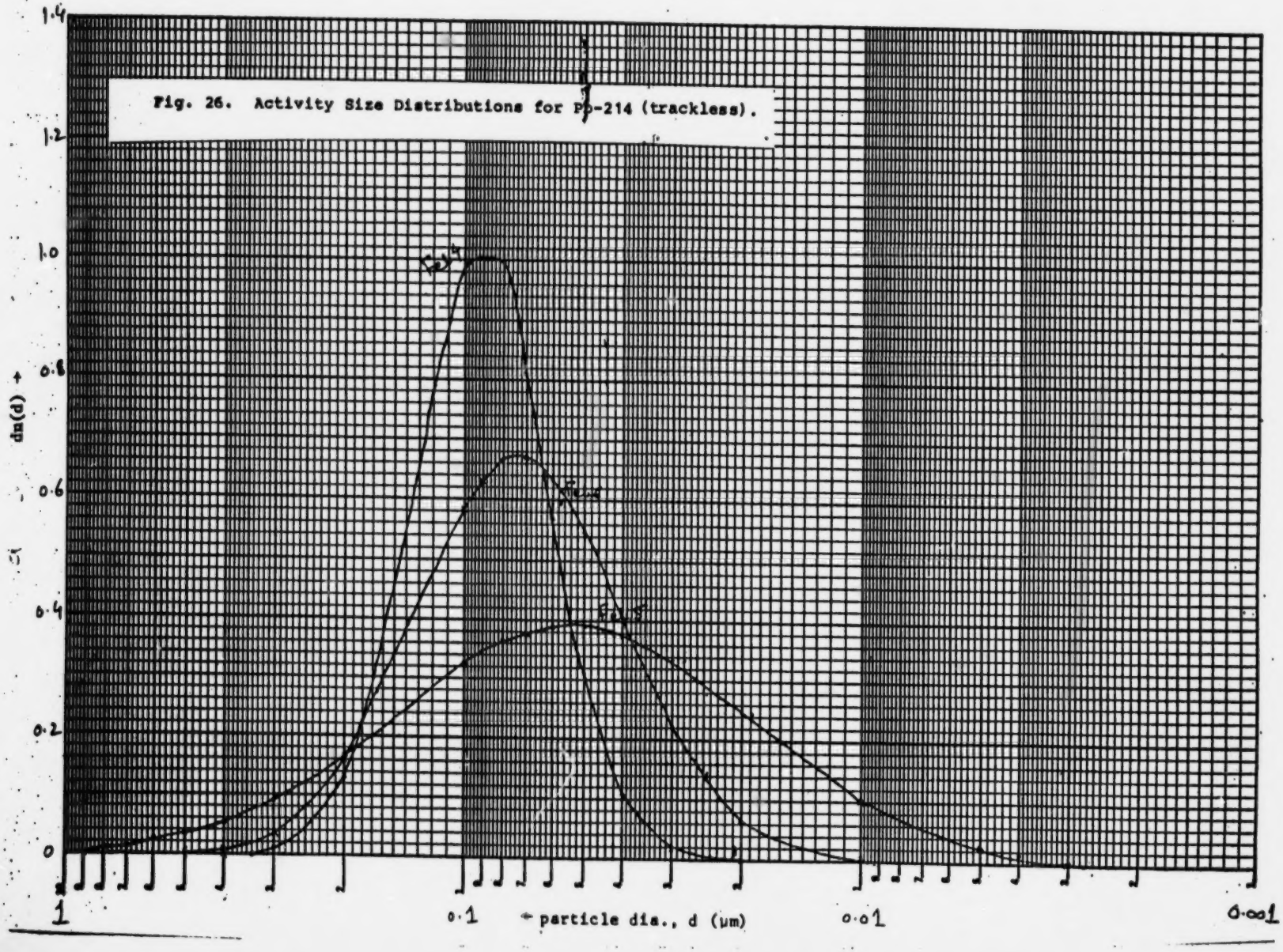


Fig. 26. Activity Size Distributions for Pb-214 (trackless).

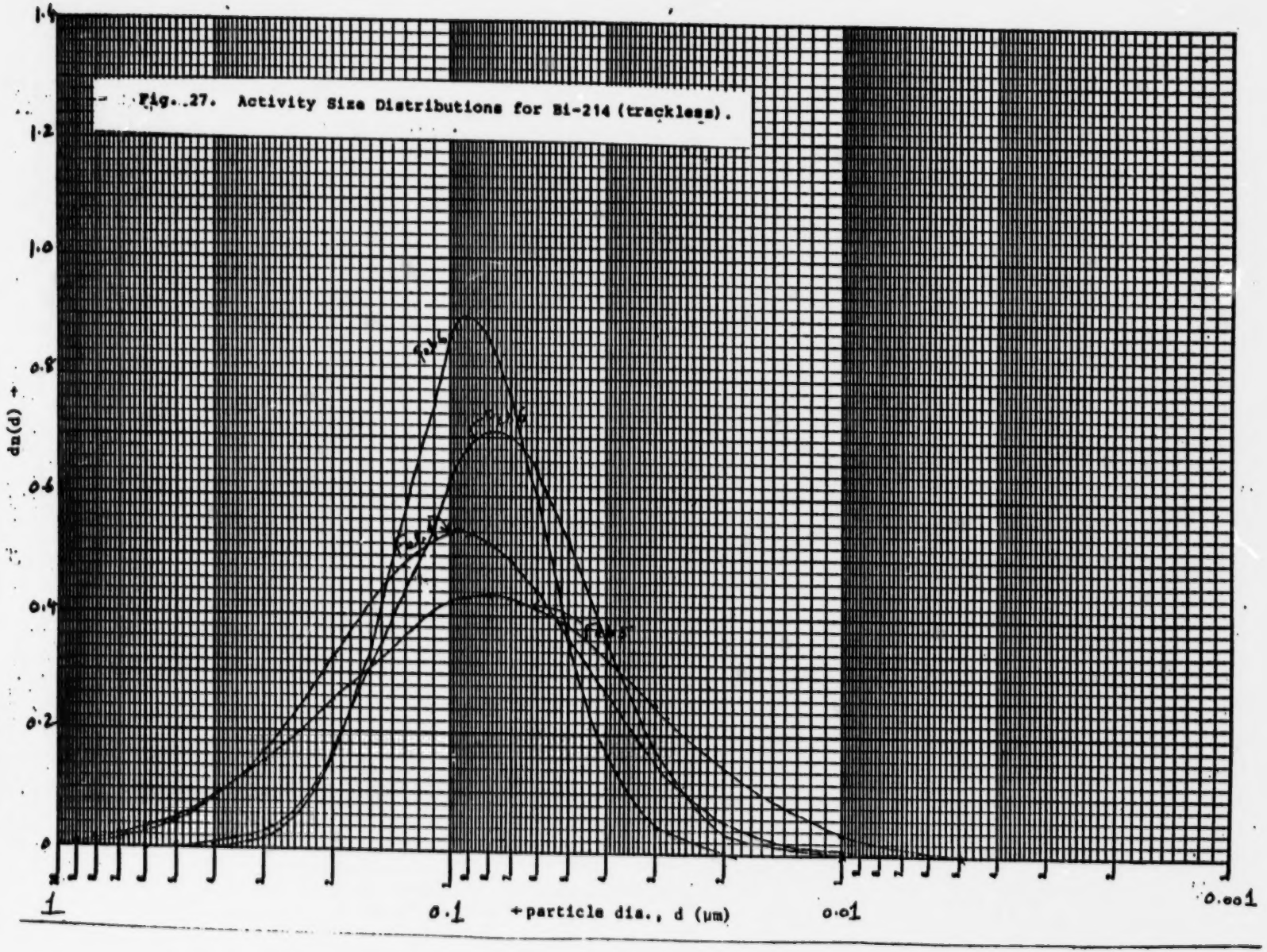


Fig. 27. Activity Size Distributions for Bi-214 (trackless).

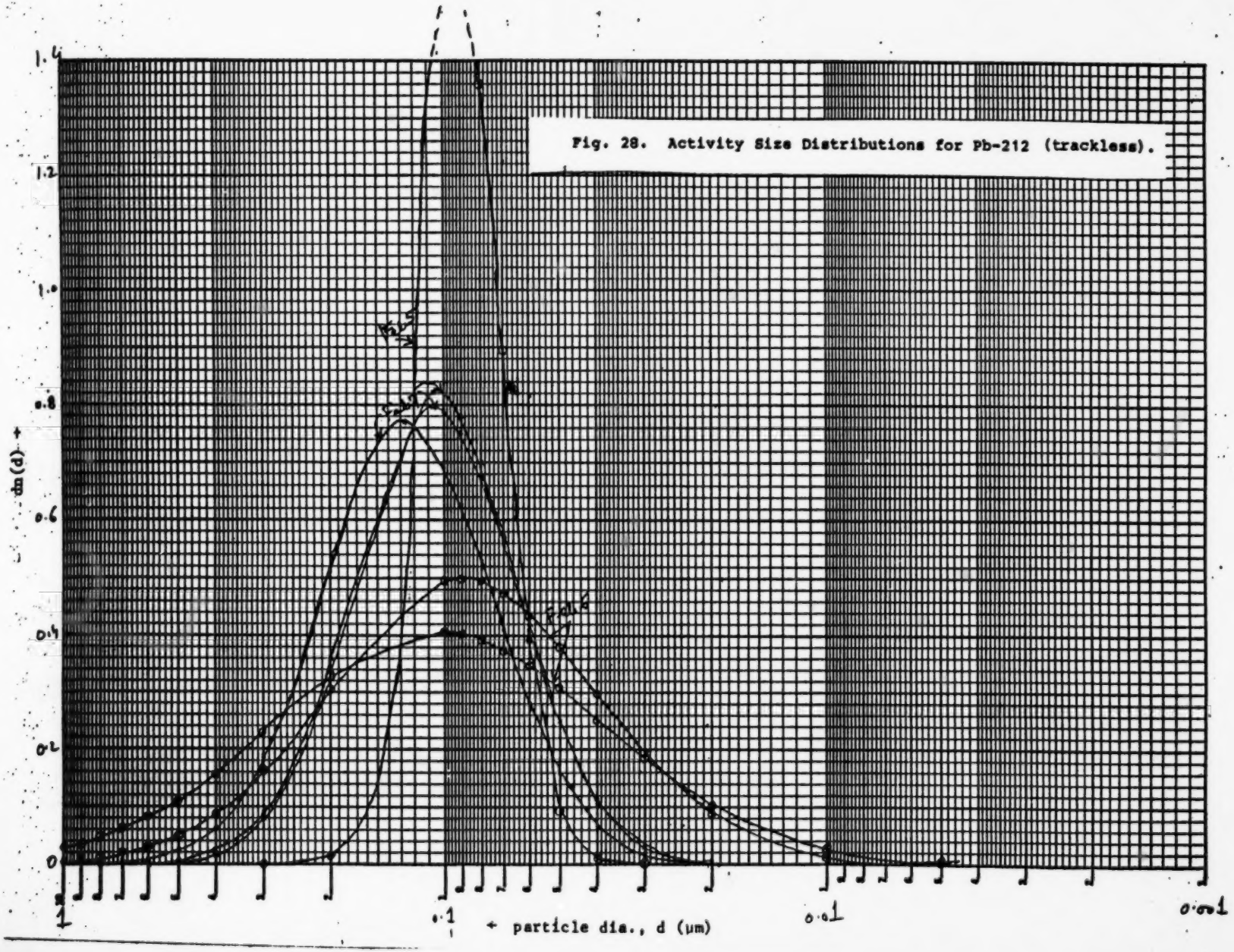


Fig. 28. Activity Size Distributions for Pb-212 (trackless).

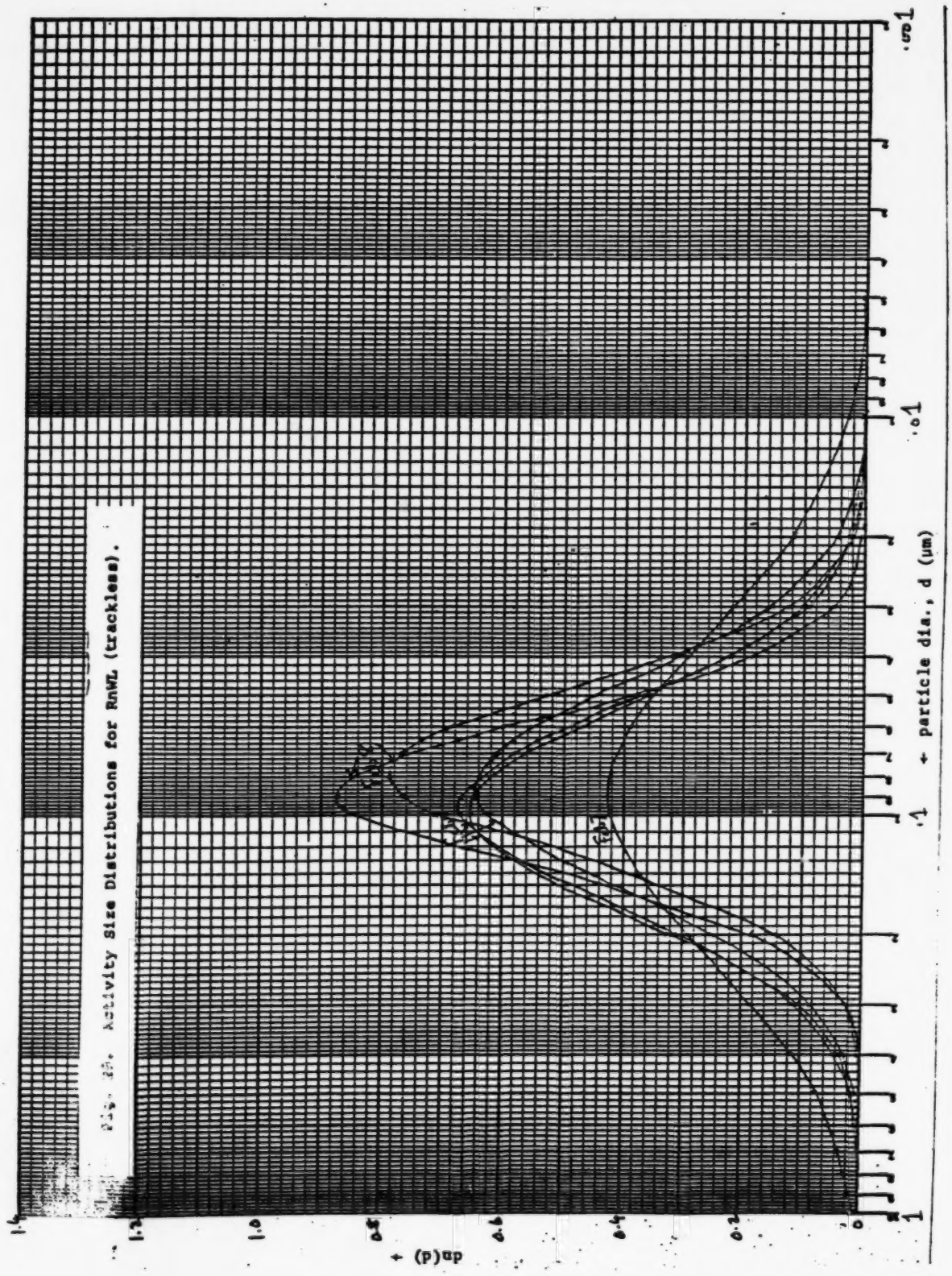


Fig. 48. Activity Size Distributions for RnWL (trackless).
dα(d) →
1.2
1.0
0.8
0.6
0.4
0.2
0
1
.1
.01
.1
1
→ particle dia., d (μm)

APPENDIX D

Schedule for Measurements

(a) Jan 29 - Feb 6

(b) Feb 7 - Feb 8

(a) Jan 29 - Feb 6

Schedule Revised on January 25, 1985.

Sampling Time = 10 mins for all measurements.

Diffusion Batteries: DBs counting: 2-4, 9-12, 85-95,240-250 (min)

Extra count for reference filters: 650-750 (min)

Sample #1. Ufs counting: 2-5, 9-25, 40-70, 360-460 (min)

Ref., D.B.#3
D.B. #4 & 5 Sampling: 8.00-8.10
Counting: 8.12-8.14, 8.19-8.22, 9.35-9.45, 12.10-12.20

Extra count for reference filter: 6.50-8.30

Sample #2
Ref., D.B. #3 Sampling: 8.13-8.23
Counting: 8.25-8.27, 8.32-8.35, 10.00-10.10, 12.23-12.33

Extra count for reference filter: 7.03-8.43

Unattached Fractions:

Sample #1 Sampling: 10.01-10.11
Counting: 10.13-10.16, 10.20-10.36, 10.51-11.21, 4.11-5.51

Sample #2 Sampling: 10.35-10.45
Counting: 10.47-10.50, 10.54-11.10, 11.25-11.55, 4.45-6.25

Sample #3 Counting intervals: 2-5, 9-25, 30-60, 360-460

Sampling: 12.22-12.32
Counting: 12.34-12.37, 12.41-12.57, 1.02-1.32, 6.32-8.12

Spare samples for Rn + Tn determination:

Counting intervals: 2-7, 340-350 min after 10 min sampling.

Sample #1 & #2: Sampling: 10.22-10.32
Counting: 10.34-10.39, 4.12-4.22

Sample #3 & #4: Sampling: 12.38-12.48
Counting: 12.50-12.55, 6.28-6.38

AA-1

Dated _____ Sheet AA Diffusion batteries #3 and #4
Unattached fraction wire screen

Trimet #3 Eff_____ Pump #3 flowrate _____ Combined flowrate = _____

Trimet #4 Eff_____ Pump #4 flowrate _____

Actual Time	Stopwatch time hr	min	Action to be taken
			Prepare for sampling through diffusion batteries. Load filter #3 in D.B. #3, filter #4 in D.B. #4. Pump #3 with D.B. #3, Pump #4 with D.B. #4.
_____		00	Start sampling through D.B. #3 and D.B. #4.
_____		10	Stop sampling through D.B. #3 and D.B. #4. Load filter #3 from D.B. #3 into
----------		--	Trimet #3 and filter #4 in Trimet #4.
_____		12	Start counting in Trimet #3 and Trimet #4.
----------		--	Prepare for sampling (sample #2) through both D.B.s (filter #5 in D.B. #3 and filter #6 in D.B. #4).
_____		13	Start sampling through both D.B.s.
----------		--	
_____		14	Stop counting in Trimet #3 and Trimet #4.
----------		--	
			Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
_____		19	Start counting in Trimet #3 and Trimet #4.
----------		--	
_____		22	Stop counting in Trimet #3 and Trimet #4
----------		--	
			Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
			Remove (and save) both filters from Trimet #3 and #4.
_____		23	Stop sampling in D.B. #3 and D.B. #4. Load filter #5 in Trimet #3 and filter
----------		--	#6 in Trimet #4.
_____		25	Start counting in Trimet #3 and Trimet #4.
----------		--	
_____		27	Stop counting in Trimet #3 and Trimet #4.
----------		--	
			Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____

AA-2

Dated _____ Sheet AA D.B. #3 and 4 Wire screen

Actual Time	Stopwatch time hr	min	Action to be taken
_____		32	Start counting in Trimet #3 and Trimet #4
----------		--	
_____		35	Stop counting in Trimet #3 and Trimet #4
----------		--	
			Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
			Remove (and save) both filters from Trimets #3 and #4.
			Load filter #3 in Trimet #3 and filter #4 in Trimet #4.
_____	1	35	Start counting in Trimet #3 and Trimet #4
----------		--	
_____	1	45	Stop counting in Trimet #3 and Trimet #4
----------		--	
			Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
			Remove (and save) both filters from Trimets.
			Load filter #5 in Trimet #3 and filter #6 in Trimet #4.
			Prepare for sampling through the wire screen.
			Load filter #7 in the wire screen filter holder.
			Join pump #3 and pump #4 together to sample through the wire screen.
_____	2	00	Start counting in Trimet #3 and Trimet #4.
----------		--	
_____	2	01	Start sampling through the wire screen
----------		--	
_____	2	10	Stop counting in Trimet #3 and Trimet #4.
----------		--	
			Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
			Remove (and save) filter #5 and filter #6 from the Trimets
_____	2	11	Stop sampling through the wire screen
----------		--	Load filter #7 from the wire screen into Trimet #3

AA-3

Dated _____ Sheet AA D.B. #3 and #4 Wire screen

Actual Time	Stopwatch time hr	min	Action to be taken
_____	2	13	Start counting in Trimet #3.
----------		---	
_____	2	16	Stop counting in Trimet #3.
----------		---	Record counts _____
_____	2	20	Start counting in Trimet #3. Prepare for sample #2 of wire screen.
----------		--	Load filter #8 in wire screen filter holder. Use pump #3 and pump #4 joined together.
			See sheet AA-a or continue
_____	2	35	Start sampling through wire screen.
----------		--	
_____	2	36	Stop counting in Trimet #3
----------		--	Record counts _____
_____	2	45	Stop sampling through wire screen. Load filter #8 from the wire screen
----------		--	into Trimet #4
_____	2	47	Start counting in Trimet #4.
----------		--	
_____	2	50	Stop counting in Trimet #4
----------			Record counts _____
_____	2	51	Start counting in Trimet #3
----------		--	
_____	2	54	Start counting in Trimet #4
----------		--	
_____	3	10	Stop counting in Trimet #4
----------			Record counts _____
_____	3	21	Stop counting in Trimet #3
----------		--	Record counts _____
			Remove (and save) filter #7 from Trimet #3 for above ground counting.
_____	3	25	Start counting in Trimet #4
----------		--	

LUNCH BREAK

AA-4

Dated _____ Sheet AA D.B. #3 and #4 Wire screen

Actual Time	Stopwatch time hr	min	Action to be taken
_____	3	55	Stop counting in Trimet #4
----------			Record counts _____
			Remove (and save) filter #8 from Trimet #4 for above ground counting
_____	4	10	Load filter #3 in Trimet #3 and filter #4 in Trimet #4.
----------		--	Start counting in Trimet #3 & Trimet #4. Prepare for sampling (sample #3) through the wire screen. Load filter #9 in the wire screen filter holder. (Pump #3 and pump #4 joined together)
_____	4	20	Stop counting in Trimet #3 and Trimet #4.
----------		--	Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
			Remove (and discard) filters from Trimet #3 and Trimet #4. Load filter #5 in Trimet #3 and filter #6 in Trimet #4.
_____	4	22	Start sampling through the wire sreen
----------		--	
_____	4	23	Start counting in Trimet #3 and Trimet #4
----------		--	
_____	4	32	Stop sampling through the wire screen
----------		--	
_____	4	33	Stop counting in Trimet #3 and Trimet #4.
----------		--	Trimet #3 - Record counts _____
			Trimet #4 - Record counts _____
			Remove (and discard) both filters from Trimet #3 and Trimet #4
			Quickly load filter #9 from wire screen filter holder into Trimet #3
_____	4	34	Start counting in Trimet #3
----------		--	
_____	4	37	Stop counting in Trimet #3
----------			Record counts _____

See sheet AA-b or continue

_____	4	41	Start counting in Trimet #3
----------		--	

AA-5

Dated _____ Sheet AA D.B. #3 and #4 Wire screen

Actual Time	Stopwatch time hr	min	Action to be taken
_____	4	57	Stop counting in Trimet #3
			Record counts _____
_____	5	02	Start counting in Trimet #3
		--	
	START PACKING UP TO LEAVE		
_____	5	32	Stop counting in Trimet #3
			Record counts _____
			Remove (and save) filter #9 from Trimet #3 for above ground counting.
	END OF UNDERGROUND WORK		
	See sheet AA-a or continue		
_____	8	00	Start preparing for counting. Load filter #7 in Trimet #3.
		--	
_____	8	11	Start counting in Trimet #3
		--	
			Load filter #8 in Trimet #4
_____	8	45	Start counting in Trimet #4
		--	
_____	9	51	Stop counting in Trimet #3
		--	Record counts _____
			Remove (and discard) filter #7
_____	10	25	Stop counting in Trimet #4
		--	Record counts _____
			Load filter #9 in Trimet #3
_____	10	32	Start counting in Trimet #3
	See sheet AA-b or continue		
REMINDER:	Check pump flow rates and plug in chargers		
_____	12	12	Stop counting in Trimet #3
			Record counts _____
			Remove (and discard) filter #9
	END OF THE DAY		

AA-a

Actual Time	Stopwatch time hr	min	Action to be taken
			Load filter #W1 in open face filter holder.
_____	2	22	Sample through filter #W1.
----------		--	
_____	2	32	Stop sampling. Load filter #W1 in Trimet #4.
----------		--	
_____	2	34	Start counting in Trimet #4.
----------		--	
_____	2	35	Start sampling through wire screen.
----------		--	
_____	2	36	Stop counting in Trimet #3.
----------			Record counts _____
_____	2	39	Stop counting in Trimet #4.
----------		--	Record counts _____

See the schedule (Sheet AA-3)

_____	8	00	Load filter #7 in Trimet #3. Load filter #W1 in Trimet #4
----------		--	
_____	8	11	See schedule.
_____	8	12	Start counting in Trimet #4.
----------		--	
_____	8	22	Stop counting in Trimet #4
----------		--	Record counts _____
			Remove (and discard) filter #W1 from Trimet #4.

See the schedule (Sheet AA-5)

AA-b

Actual Time	Stopwatch time		Action to be taken
	hr	min	
_____	4	35	Load filter #W3 in an open face filter holder.
----------		--	
_____	4	37	Stop counting in Trimet #3.
----------		--	Record counts _____
_____	4	38	Start sampling through #W3.
----------		--	
_____	4	41	Start counting in Trimet #3.
----------		--	
_____	4	48	Start sampling through filter #W3. Load filter #W3 in Trimet #4.
----------		--	
_____	4	50	Start counting in Trimet #4.
----------		--	
_____	4	55	Stop counting in Trimet #4.
----------		--	Record counts _____
	See the schedule (Sheet AA-4)		
_____	10	26	Load filter #W3 in Trimet #4.
----------		--	
_____	10	28	Start counting in Trimet #4.
----------		--	
_____	10	38	Stop counting in Trimet #4.
----------		--	Record counts _____
	See the schedule (Sheet AA-5)		

Dated _____ Sheet BB Diffusion batteries Ref. & #5
Unattached fraction wire screen Ref.

Trimet #1 Eff ____ Pump #1 flowrate _____ Combined flowrate = _____

Trimet #2 Eff ____ Pump #2 flowrate _____

Actual Time	Stopwatch time hr	min	Action to be taken
			Prepare for sampling through diffusion batteries. Load filter #A in the Ref. and filter #B in D.B. #5. Pump #1 with the Ref. Pump #2 with D.B. #5.
_____		00	Start sampling through the Ref and D.B. #5.
_____		10	Stop sampling through the Ref and D.B. #5. Load filter #A from the Ref into
----------		--	Trimet #1 and filter #B in Trimet #2.
_____		12	Start counting in Trimet #1 and Trimet #2.
----------		--	Prepare for sampling (sample #2) through both D.B.s (filter #C the Ref and filter #D in D.B. #5).
_____		13	Start sampling through both D.B.s.
----------		--	
_____		14	Stop counting in Trimet #1 and Trimet #2.
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
_____		19	Start counting in Trimet #1 and Trimet #2.
----------		--	
_____		22	Stop counting in Trimet #1 and Trimet #2
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
			Remove (and save) both filters from Trimet #1 and #2.
_____		23	Stop sampling in the Ref and D.B. #5. Load filter #C in Trimet #1 and filter
----------		--	#D in Trimet #2.
_____		25	Start counting in Trimet #1 and Trimet #2.
----------		--	
_____		27	Stop counting in Trimet #1 and Trimet #2.
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____

Dated _____ Sheet BB the Ref and D.B.#5 Wire screen Ref.

Actual Time	Stopwatch time hr	min	Action to be taken
_____		32	Start counting in Trimet #1 and Trimet #2
----------		--	
_____		35	Stop counting in Trimet #1 and Trimet #2
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
			Remove (and save) both filters from Trimets #1 and #2.
			Load filter #A in Trimet #1 and filter #B in Trimet #2.
_____	1	35	Start counting in Trimet #1 and Trimet #2
----------		--	
_____	1	45	Stop counting in Trimet #1 and Trimet #2
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
			Remove (and save) both filters from Trimets.
			Load filter #C in Trimet #1 and filter #D in Trimet #2.
			Prepare for sampling through the wire screen.
			Load filter #E in the wire screen reference filter holder.
	—		Join pump #1 and pump #2 together to sample through the wire screen reference.
_____	2	00	Start counting in Trimet #1 and Trimet #2.
----------		--	
_____	2	01	Start sampling through the wire screen reference.
----------		--	
_____	2	10	Stop counting in Trimet #1 and Trimet #2.
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
			Remove (and save) filter #C and filter #D from the Trimets
_____	2	11	Stop sampling through the wire screen reference.
----------		--	
			Load filter #E from the wire screen reference into Trimet #1

BB-3

Dated _____ Sheet BB the Ref & D.B.#5 Wire screen Ref.

Actual Time	Stopwatch time hr	min	Action to be taken
_____	2	13	Start counting in Trimet #1.
----------		---	
_____	2	16	Stop counting in Trimet #1.
----------		---	Record counts _____
_____	2	20	Start counting in Trimet #1.
----------		--	Prepare for sample #2 of wire screen reference. Load filter #G in wire screen reference filter holder. Use pump #1 and pump #2 joined together.
			See sheet AA-a or continue
_____	2	35	Start sampling through wire screen.
----------		--	
_____	2	36	Stop counting in Trimet #1
----------		--	Record counts _____
_____	2	45	Stop sampling through wire screen
----------		--	reference. Load filter #8 from the wire screen reference into Trimet #2 .
_____	2	47	Start counting in Trimet #2.
----------		--	
_____	2	50	Stop counting in Trimet #2
----------			Record counts _____
_____	2	51	Start counting in Trimet #1
----------		--	
_____	2	54	Start counting in Trimet #2
----------		--	
_____	3	10	Stop counting in Trimet #2
----------			Record counts _____
_____	3	21	Stop counting in Trimet #1
----------		--	Record counts _____
			Remove (and save) filter #E from Trimet #1 for above ground counting.
_____	3	25	Start counting in Trimet #2
----------		--	

LUNCH BREAK

BB-4

Dated _____ Sheet BB the Ref & D.B.#5 Wire screen Ref.

Actual Time	Stopwatch time hr	min	Action to be taken
_____	3	55	Stop counting in Trimet #2
----------			Record counts _____
			Remove (and save) filter #G from Trimet #2 for above ground counting
_____	4	10	Load filter #A in Trimet #1 and filter #B in Trimet #2.
----------		--	Start counting in Trimet #1 and Trimet #2. Prepare for sampling (sample #3) through the wire screen. Load filter #H in the wire screen filter holder. (Pump #1 and pump #2 joined together)
_____	4	20	Stop counting in Trimet #1 and Trimet #2.
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
			Remove filters from Trimet #1 and Trimet #2. Save filter #A for above ground counting. Load filter #C in Trimet #1 and filter #D in Trimet #2.
_____	4	22	Start sampling through the wire sreen
----------		--	
_____	4	23	Start counting in Trimet #1 and Trimet #2
----------		--	
_____	4	32	Stop sampling through the wire screen
----------		--	
_____	4	33	Stop counting in Trimet #1 and Trimet #2.
----------		--	
			Trimet #1 - Record counts _____
			Trimet #2 - Record counts _____
			Remove both filters from Trimet #1 and Trimet #2. Save filter #C for above ground counting.
			Quickly load filter #H from wire screen filter holder into Trimet #1
_____	4	34	Start counting in Trimet #1
----------		--	

See sheet BB-b or continue

_____	4	37	Stop counting in Trimet #1
----------			Record counts _____

BB-5

Dated _____ Sheet BB the Ref & D.B.#5 Wire screen

Actual Time	Stopwatch time hr	min	Action to be taken
_____	4	41	Start counting in Trimet #1
----------		--	
_____	4	57	Stop counting in Trimet #1
----------			Record counts _____
_____	5	02	Start counting in Trimet #1
----------		--	
_____			START PACKING UP TO LEAVE _____
_____	5	32	Stop counting in Trimet #1
			Record counts _____
			Remove (and save) filter #H from Trimet #1 for above ground counting.
_____			END OF UNDERGROUND WORK _____
			See sheet AA-a or continue
_____	8	00	Start preparing for counting. Load filter #E in Trimet #1.
----------		--	
_____	8	11	Start counting in Trimet #1
----------		--	
			Load filter #G in Trimet #2
_____	8	45	Start counting in Trimet #2
----------		--	
_____	9	51	Stop counting in Trimet #1
----------		--	Record counts _____
			Remove (and discard) filter #E
_____	10	25	Stop counting in Trimet #2
----------		--	Record counts _____
			Load filter #H in Trimet #1
_____	10	32	Start counting in Trimet #1

			See sheet AA-b or continue
REMINDER:			Check pump flow rates and plug in chargers
_____	12	12	Stop counting in Trimet #1
----------			Record counts _____
			Remove (and discard) filter #H
_____			END OF THE DAY _____

BB-a

Actual Time	Stopwatch time hr	min	Action to be taken
			Load filter #W2 in open face filter holder
_____	2	22	Start sampling through filter #W2
----------		--	
_____	2	32	Stop sampling. Load filter #W2 in Trimet #2.
----------		--	
_____	2	34	Start counting in Trimet #2.
----------		--	
_____	2	35	Start sampling through the wire screen references.
----------		--	
_____	2	36	Stop counting in Trimet #1.
----------		--	Record counts _____
_____	2	39	Stop counting in Trimet #2.
----------		--	Record counts _____

See the schedule (Sheet BB-3)

_____	8	00	Load filter #E in Trimet #1. Load filter #W2 in Trimet #2.
----------		--	
_____	8	11	See schedule.
_____	8	12	Start counting in Trimet #2.
----------		--	
_____	8	22	Stop counting in Trimet #2.
----------		--	Record counts _____
			Remove (and discard) filter #W2 from Trimet #2.

See the schedule (Sheet BB-5)

Actual Time	Stopwatch time hr	min	Action to be taken
_____	4	35	Load filter #W4 in an open face filter holder.
----------		--	
_____	4	37	Stop counting in Trimet #.
----------		--	Record counts _____
_____	4	38	Start sampling through filter #W4.
----------		--	
_____	4	41	Start counting in Trimet #1.
----------		--	
_____	4	48	Stop sampling through filter #W4.
----------		--	Load filter #W4 in Trimet #2.
_____	4	50	Start counting in Trimet #2.
----------		--	
_____	4	55	Stop counting in Trimet #2.
----------			Record counts _____
	See the schedule (Sheet BB-4)		
_____	10	26	Load filter #W4 in Trimet #2.
----------		--	
_____	10	28	Start counting in Trimet #2.
----------		--	
_____	10	38	Stop counting in Trimet #2.
----------		--	Record counts _____
			Load filter #A in Trimet #2.
_____	10	50	Start counting in Trimet #2.
----------		--	Load filter #C in Trimet #4.
_____	11	03	Start counting in Trimet #4.
----------		--	
_____	12	12	Stop counting in Trimet #1.
----------		--	Record counts _____
_____	12	30	Stop counting in Trimet #2
----------			Record counts _____
_____	12	43	Stop counting in Trimet #4
----------			Record counts _____

END OF DAY

(b) Feb 7 - Feb 8

Sampling and Counting Schedule:

	Species & Sample No.	Sampling Time	Counting Time	Counting Interval
Diffusion Batts.	ThB #1	8.00-8.15	12.45-1.00	270-285
Unattached Fr.	ThB #1	8.17-8.32	1.02-1.32	270-300
Diffusion Batts.	Rn ds #1	8.35-8.40	8.42-8.47	2-7
Unattached Fr.	Rn ds #1	8.45-8.50	8.52-8.57	2-7
Diffusion Batts.	Rn ds #2	9.05-9.10	9.12-9.17	2-7
Unattached Fr.	Rn ds #2	9.15-9.20	9.22-9.27	"
Diffusion Batts.	Rn ds #3	9.35-9.40	9.42-9.47	"
Unattached Fr.	Rn ds #3	9.45-9.50	9.52-9.57	"
Diffusion Batts.	Rn ds #4	10.05-10.10	10.12-10.17	"
Unattached Fr.	Rn ds #4	10.15-10.20	10.22-10.27	"
Diffusion Batts.	ThB #2	11.25-11.40	5.10-5.25	330-345
Unattached Fr.	ThB #2	11.42-11.57	5.27-5.57	330-360
Unattached Fr.	ThB #3	12.03-12.18	5.48-6.18	"
Diffusion Batts.	ThB #3	12.35-12.50	6.20-6.35	330-345
Diffusion Batts.	ThB #4	12.57-1.12	6.42-6.57	"
Unattached Fr.	ThB #4	1.15-1.30	7.00-7.30	330-360

Dated: _____

AA		BB	
Trimet #3 - Eff Trimet #4 - Eff	Pumps #3 & #4 D.B.3, D.B.4 and WS	Trimet #1 - Eff Trimet #2 - Eff Trimet #5 - Eff	Pumps #1 & #2 D.B.5, Ref. and WS Ref.

Actual Time	Stopwatch time hr	min	Action to be taken
			Prepare for sampling for ThB through diffusion batteries and reference. Filter #A (ref.) - #1 (D.B.3) #B (D.B.5) - #2 (D.B.4) Pump #3 - D.B. #3, #1 ref. #4 - D.B. #4, #2 D.B.5
_____		00	Start sampling through D.B.s. Load filters in wire screen and reference for sampling unattached ThB. Filter #C (ref) #3 (WS)
_____		15	Stop sampling through diffusion batteries.
----------		--	Remove pumps and join pump #1 and 2 to WS ref., pump #3 and 4 to WS
_____		17	Start sampling through WS and WS ref.
----------		--	Remove filters from D.B.s and their reference and save them for later counting (underground). Load fresh filters in D.B.s for sampling Rn daughters. Filter #D - Ref. - #4 (D.B.3) #E - (D.B.5) - #5 (D.B.4)
_____		32	Stop sampling through wire screen and reference. Save filters for later
----------		--	counting (underground). Quickly join pump #1 to D.B. ref., #2 to D.B.5, #3 to D.B.3 and #4 to D.B.4.
_____		35	Start sampling through D.B.s for radon daughters. Load fresh filters for wire
----------		--	screen sampling. Filter #G (ref.), filter #6 (WS).
_____		40	Stop sampling through D.B.s. Quickly load filters in Trimets.
----------		--	Ref. - T#1 D.B.3 - T#3 D.B.5 - T#2 D.B.4 - T#4
_____		42	Start counting in all Trimets. Join pump #1 and 2 to WS ref.
----------		--	pump #3 and 4 to WS
_____		45	Start sampling through WS and its ref.
----------		--	
_____		47	Stop counting in all Trimets.
----------		--	Record counts _____ (Trimet #1 or 3) _____ (Trimet #2 or 4) (Discard all filters)

Actual Time	Stopwatch time		Action to be taken
	hr	min	
_____		50	Stop sampling through WS and WS ref. Quickly load filters into Trimets.
----------		--	From ref to Trimet #1 From WS to Trimet #3
_____		52	Start counting in Trimets (5 min count) Load fresh filters for D.B. sampling
----------		--	for Rn ds. Filter #H - ref #7 - D.B.3 #J - D.B.5 #8 - D.B.4
_____		57	Stop counting in Trimets.
----------		--	
			Record counts _____ (Trimet #1 or 3)
			(Discard filters) Join pumps in the usual manner for D.B. sampling. Pump #1 - ref #3 D.B.3 #2 - D.B.5 #4 D.B.4
_____	1	05	Start sampling in diffusion batteries. Load fresh filters for WS sampling.
----------		--	filter #K (WS ref) #9 (WS)
_____	1	10	Stop sampling in D.B.5. Load filters in Trimets in the usual
----------		--	way. Ref - T#1 D.B.3 - T#3 D.B.5 - T#2 D.B.4 - T#4
_____	1	12	Start counting in Trimets. Join pumps for WS sampling in the usual
----------		--	way,
_____	1	15	Start sampling for WS.
----------		--	
_____	1	17	Stop counting in Trimets.
----------		--	
			Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			(Discard all filters)
_____	1	20	Stop sampling through WSs. Load filters in usual Trimets.
----------		--	Ref - T#1 WS - T#3
_____	1	22	Start counting in Trimets.
----------		--	
_____	1	27	Stop counting in Trimets.
----------		--	Record counts _____ (Trimet #1 or 3)
			(Discard filters) Prepare for sample #3 for Rn ds through D.B.s Filter #L (ref) filter #10 (D.B.3) #M (D.B.5) #11 (D.B.4) Join pumps in usual way.

Actual Time	Stopwatch time		Action to be taken
	hr	min	
_____	1	35	Start sampling through D.B.s. Load fresh filters for WS sampling
----------		--	filter #N (ref.) filter #12 (WS)
_____	1	40	Stop sampling through D.B.s. Load filters in Trimets in usual way.
----------		--	
_____	1	45	Start sampling through WS.
----------		--	
_____	1	47	Stop counting in Trimets.
----------		--	Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			(Discard all filters)
_____	1	50	Stop sampling through WS. Load filters into usual Trimets.
----------		--	
_____	1	52	Start counting in Trimets.
----------		--	
_____	1	57	Stop counting.
----------			Record counts _____ (Trimet #1 or 3)
			(Discard filters) Load fresh filters for D.B. sample #4 for Rn ds. Filter #O (ref) filter #13 (D.B.3) #P (D.B.5) #14 (D.B.4) Join pumps in usual manner.
_____	2	05	Start smpling through D.B.s. Prepare for WS sampling.
----------		--	Filter #Q (ref) filter #15 (WS)
_____	2	10	Stop sampling through D.B.s. Load filters in usual Trimets.

_____	2	12	Start counting. Join pumps for WS sampling.
----------		--	
_____	2	15	Start WS sampling.
----------		--	
_____	2	17	Stop counting.
----------		--	Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			(Discard all filters)
_____	2	20	Stop WS sampling. Load filters in usual manner.

Actual Time	Stopwatch time hr	min	Action to be taken
_____	2	22	Start counting.
_____		--	
_____	2	27	Stop counting.
_____			Record counts_____ (Trimet #1 or 3)
			(Discard filters)
			LUNCH BREAK
_____	3	20	Prepare for D.B. sample #2 for ThB. #R (ref) #16 (D.B.3) #S (D.B.5) #17 (D.B.4) Join pumps in usual way.
_____	3	25	Start sampling. Prepare for WS Sample #2 for ThB. filter #T (ref) #18 (WS)
_____	3	40	Stop sampling. Quickly join pumps to WS ref.
_____	3	42	Start sampling through WS and ref. Save filters from D.B.s for above ground counting.
_____	3	57	Stop sampling through WS and ref. Do not remove pumps. Change fresh filters in WS and ref. filter #U (ref) #19 (WS) Save previous filters for above ground counting.
_____	4	03	Start sampling through WS and ref.
_____	4	18	Stop sampling through WS and ref. Remove and save filters for above ground counting. Load fresh filters for D.B. sample #3 #V (ref) #20 (D.B.3) #W (D.B.5) #21 (D.B.4) Join pumps in usual way.
_____	4	35	Start sampling through D.B.s. Load filter #A, B in Trimets #1, 2, filter #1, 2 in Trimets #3, 4
_____	4	45	Start counting in all Trimets.
_____	4	50	Stop sampling through D.B.s. Do not remove pumps. Save filters for above ground counting. Load fresh filters for sample #4 with D.B.s #X (ref) #22 (D.B.3) #Y (D.B.5) #23 (D.B.4)

Actual Time	Stopwatch time		Action to be taken
	hr	min	
_____	4	57	Start sampling through D.B.s.
----------		--	
_____	5	00	Stop counting in all Trimeta.
----------		--	Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			Discard all filters and quickly load filter #C in Trimet #1 filter #3 in Trimet #3
_____	5	02	Start counting in Trimet #1 and 3. Prepare for WS sample #4, filter #2
----------		--	(ref.)
_____	5	12	Stop sampling through D.B.s #24 (WS). Join pumps to WS and ref.

_____	5	15	Start sampling through WS and ref. Save filters from D.B.s for above
----------			ground counting.
_____	5	30	Stop sampling through WS and ref. Save filters for above ground counting.

_____	5	32	Stop counting in Trimet #1 and 3.
----------		--	Record counts _____ (Trimet #1 or 3)
			(Discard filters)
_____			END OF UNDERGROUND WORK _____
_____	9	00	Load filters #R and S in Trimets #1 and 2, #16 and 17 in Trimets #3 and 4
----------		--	
_____	9	10	Start counting in all Trimets.
----------		--	
_____	9	25	Stop counting in all Trimets.
----------		--	Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			Quickly discard these filters and load filter #T Trimet #1 filter #18 Trimet #3
_____	9	27	Start counting. Load filter #U Trimet #2
----------		--	#19 Trimet #4
_____	9	48	Start counting in Trimet #2 and 4.
----------		--	

Actual Time	Stopwatch time hr	min	Action to be taken
_____	10	18	Stop counting in Trimet #2 and 4
----------		--	Record counts _____ (Trimet #2 or 4)
			Quickly discard these filters and load filter #V & W in Trimet #1 and 2 filter #20 & 21 in Trimet #3 and 4
_____	10	20	Start counting in all Trimets.
----------		--	
_____	10	35	Stop counting in all Trimets.
----------		--	Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			(Discard all filters)
			Load filters #X & Y in Trimet #1 & 2 filter #22 & 23 in Trimet #3 & 4
_____	10	42	Start counting in all Trimets.
----------		--	
_____	10	57	Stop counting in all Trimets.
----------		--	Record counts _____ (Trimet #1 or 3)
			_____ (Trimet #2 or 4)
			Discard all filters and quickly load filters #2· - Trimet #1 #24 - Trimet #3
_____	11	00	Start counting.
----------		--	
_____	11	30	Stop counting.
----------		--	Record counts _____ (Trimet #1 or 3)
			(Discard all filters)

END OF DAY